SOIL NEMATODE COMMUNITIES AS INFLUENCED BY FERTILITY MANAGEMENT PRACTICES, GROWTH AND YIELD OF COMMON BEANS (var. Mwitemania) IN THARAKA NITHI, KENYA

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A Thesis Submitted to Graduate School in Partial Fulfillment of the Requirements for the Award of the Degree of Master of Science in Soil Science of Chuka University

CHUKA UNIVERSITY
OCTOBER, 2025

DECLARATION AND RECOMMENDATION

Declaration

This thesis is my original work and has not been presented for any award of a diploma or conferment of a degree in any other institution.

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Recommendation

This thesis has been examined, passed, and submitted with our approval as my supervisors.

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DEDICATION

This thesis is dedicated to my parents, Josphat Muraki Maina and Nancy Wangui Muraki, my husband, Vincent Kiplagat, and my son, Baraka Kiptanui, who supported my academic success with their financial support, encouragement, endless sacrifices, love, and moral guidance. This work is a testament to their assistance; may Almighty God bless them.

ACKNOWLEDGEMENT

I begin by expressing my deepest gratitude to Almighty God for His abundant grace, guidance, and blessings that have sustained me throughout this academic journey. This accomplishment would not have been possible without His divine provision. Special thanks go to Chuka University for allowing me to pursue my Master of Science in Soil Science Degree and for fostering a supportive and enriching environment. My heartfelt appreciation goes to the Faculty of Agriculture and the Department of Plant Sciences for their dedication and commitment to advancing knowledge and excellence. To my supervisors, Dr. Haggai O. Ndukhu, Dr. Carolyne A. Omukoko, and Dr. Solveig Haukeland, I would like to express my sincere gratitude for your expert guidance, insightful feedback, and unwavering encouragement throughout this process. Your mentorship has been a cornerstone of my scholarly and research growth. Heartfelt gratitude is extended to Harriet Kari for her generosity in providing a portion of land for my research. Her selflessness and support were instrumental in enabling me to carry out this study successfully. Sincere appreciation goes to Dr. Solveig Haukeland from the ICIPE Nematology Laboratory, who is one of my supervisors, for granting me access to essential resources, tools, and expertise in laboratory work. Gratitude is further extended to Miriam Kungu from ICIPE for connecting me to the ICIPE nematology laboratory. Her guidance and assistance were important in facilitating my work. Acknowledgment is also due to Chuka University Plant Sciences Laboratory for providing the necessary facilities, resources, and technical support that were pivotal to the success of my research. Finally, I would like to extend my warmest thanks to my fellow students from ICIPE and Chuka University for their support, encouragement, and insightful discussions throughout this study. Their willingness to exchange knowledge, share ideas, and assist when required created a collaborative and inspiring environment that made this journey enjoyable and productive.

ABSTRACT

Common bean yield is relatively low due to soil infertility, diseases, and pests such as plant-parasitic nematodes (PPNs), as well as unfavorable climatic conditions, among other factors. PPNs have been reported to cause yield losses of up to 60% while free-living nematodes (FLN) contribute positively to soil health. The study's general objective was to evaluate the effect of fertility management practices on soil nematode communities and the yield of common beans in Tharaka Nithi County. The treatments included NPK (23.23.0), Trichoderma harzianum (45g/20 litres), farmyard manure (10 ton/ha), and a control (with no amendment), which were laid out in a randomized complete block design (RCBD) and replicated three times. Soil samples were taken from the field before bean sowing, at flowering, and after harvesting common beans in each trial. Nematodes were extracted from 200ml of soil and 5g of roots using Modified Baermann technique. Data were collected on bean growth every two weeks and on yield components. Meanwhile, nematode numbers were counted, and species diversity and evenness were calculated per plot. The data values obtained were subjected to analysis of variance using R version 4.5.0, and significant means were separated using the Least Significant Difference Test at $\alpha = 0.05$. Results showed that in both trials, Farmyard manure increased FLN in soil (941) and showed a significant difference ($p<0.05$) from all other treatments and compared to the control, which reduced FLN in soil (110). The control treatment had the highest population of PPNs in soil (773) and showed a significant difference ($p < 0.05$) from the other treatments, while Trichoderma harzianum reduced the PPN population (123) in the soil. Control treatment increased Shannon diversity (1.68), Simpson's diversity (0.78), and evenness (0.9) of PPNs as compared to *Trichoderma harzianum*, which reduced Shannon diversity (1.03), Simpson's diversity (0.49), and evenness (0.85). *Trichoderma harzianum* increased the Shannon diversity (1.35), Simpson's diversity (0.7), and evenness (0.84) of FLN compared to the control, which reduced the Shannon diversity (0.85), Simpson's diversity (0.54), and evenness (0.77). The NPK (23.23.0) treatment had the highest growth response which recorded the highest values across four intervals of data collection on height (85.80 cm), number of leaves (72.5), branches (23.54), pods (25.34) seeds (169.39), biomass (1211.72 kg/ha), and grain yield (4592.60 kg/ha), and showed significant difference ($p<0.05$) from other treatments while control had the reduced growth response of height (39.08 cm), number of leaves(19.25), branches (5.75), pods (5.87) seeds (32.67), biomass (193.24 kg/ha), and grain yield (586.42 kg/ha). *Trichoderma harzianum* had the highest number of nodules (50.5) and showed a significant difference from other treatments, while NPK (23.23.0) had the least (2.9). The NPK treatment increased PPNs in roots (46) and showed a significant difference ($p < 0.05$) from other treatments compared to Trichoderma harzianum, which reduced PPNs (2.5) in roots. Farmyard manure and *Trichoderma harzianum* emerged as promising strategies for managing PPNs while promoting beneficial nematodes to enhance common bean yields and soil health. Continuous assessment of nematode communities over multiple growing seasons is crucial for understanding the long-term effects of various soil amendments on diversity and crop productivity.

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ACRONYMS AND ABBREVIATIONS

ANOVA	**:**	Analysis of Variance
DAP	**:**	Diammonium Phosphate
FAO	**:**	Food and Agriculture Organisation of the United Nations
FAOSTAT	**:**	Food and Agriculture Organisation Corporate Statistical Database
FLN	**:**	Free-living Nematodes
ICIPE	**:**	International Centre of Insect Physiology and Ecology
KARLO	**:**	Kenya Agricultural Research and Livestock Organisation
MSW	**:**	Municipal Solid Waste
NACOSTI	**:**	National Commission for Science, Technology and Innovation
NPK	**:**	Nitrogen Phosphorus Potassium
PPNs	**:**	Plant-Parasitic Nematodes
WUE	**:**	Water-Use-Efficiency

CHAPTER ONE

INTRODUCTION

1.1 Background Information

Common beans (*Phaseolus vulgaris*) belong to the Fabaceae family, which includes other legumes such as soybeans, peas, chickpeas, and alfalfa. Common beans account for over ¾ of the world's annual production of 8.5 million metric tons (Rodriguez & Creamer, 2014). In Africa, Tanzania is the largest producer of common beans, followed by Uganda, Kenya, Ethiopia, and Rwanda, accounting for 17.52, 15.28, 11.16, 8.25, and 6.59% respectively (Mathobo & Mathobo, 2024). In Kenya, common beans are mainly produced in the Western, Eastern, Central, and Rift Valley regions, accounting for 31, 24, 20, and 13%, respectively, on an estimated 700,000 ha (Farrow *et al.*, 2020).

Beans are significant because they provide complex carbohydrates, protein, and micronutrients that are valuable to the human population (FAOSTAT, 2019). Farmers use common beans in crop rotation because nitrogen is an essential nutrient for plant growth. Common beans improve soil fertility through nitrogen fixation, which means they harbor rhizobium bacteria in their nodules that convert atmospheric nitrogen into plant-available forms (FAOSTAT, 2019). Bean yields in Kenya are as low as 750 kg/ha in monocropping and even lower than 335 kg/ha under mixed cropping systems, whereas the potential is 1500-2000 kg/ha (Mataa *et al.*, 2021). This could be attributed to pests like plant-parasitic nematodes, low soil fertility, poor varieties, and water stress, among other agronomic factors. The potential for nodulation of leguminous crops is adversely affected by infection with root-knot nematodes, thereby interfering with nitrogen fixation. According to Talwana *et al.* (2016), common bean yield losses have been recorded by up to 60% due to heavy infestation of root-knot nematodes.

Nematodes are worms that are microscopic and live in soil pores formed through soil processes (Yeates *et al.*, 2009). They move in water films, which stick to soil particles. The estimated population of species is more than half a million, whereas free-living species have the largest populations in soils, freshwater habitats, and oceans. At the same time, parasitic types form the smaller group (Ferris *et al.*, 2012). Soil nematode communities comprise free-living nematodes and plant-parasitic nematodes. Free-living nematodes are useful indicators of soil health (Yeates, 2003), and entomopathogenic nematodes are utilized for the biological control of insects (Schratzberger *et al.,* 2019; Neher, 2001). They play crucial roles in the soil, like providing food sources to soil microbes, improving water holding capacity and soil structure, mineralization, and decomposition of organic matter (Lu *et al*., 2020; *Nisa et al*., 2021). They are primarily found in marine and soil environments. Nematodes are classified into five trophic levels: omnivores, bacterivores, herbivores, fungivores, and predators (Yeates *et al*., 1993; Zullini, 2018). Plant-parasitic nematodes (PPNs) are considered a primary biological constraint worldwide in various crops, resulting in considerable losses in production of up to 20% (Hamida *et al*., 2015). A key plant-parasitic nematode, the *Meloidogyne* spp. cause losses of up to 85% (Coyne *et al*., 2014). *Meloidogyne javanica, M. incognita, and M. arenaria* are the most encountered in tropical regions and have a wide host range (Bebber *et al*., 2014).

Strategies like cultural practices, nematicides, organic amendments, and resistant varieties have been established to manage plant-parasitic nematodes (Sikora & Roberts, 2018). Some of these strategies have limitations, such as nematicides, which are costly and not environmentally friendly (Sasaneli *et al*., 2021). Cultural practices are labor-intensive and time-consuming. Resistant varieties may not be efficient when a field has multiple nematode species (Oka *et al*., 2000). Organic amendments, such as farmyard manure, suppress plant-parasitic nematodes, increase free-living nematodes, and improve soil health due to the added nutrients in the soil (Thoden *et al*., 2011). The addition of farmyard manure influences nematodes due to the incorporation of organic matter; nematodes can respond to manure amendments by increasing their activity levels and numbers (Semenov *et al*., 2021).

Farmyard manure can indirectly affect soil organisms through changes in physical properties (such as porosity and aggregation), soil pH, soil organic matter levels, and productivity (Bunemann *et al*., 2006). Chemical fertilizers influence soil organisms, stimulating the growth of nitrifying and ammonifying microorganisms, as well as the proliferation of bacteria that form spores and promote crop residue mineralization (Pahalvi *et al*., 2021). Chemical fertilizers, such as NPK, are added to enhance soil fertility (Bhatt *et al*., 2019). These fertilizers can influence both parasitic and free-living nematodes, often resulting in shifts in trophic structure, diversity, and abundance (Fan *et al*., 2025).

Trichoderma harzianum is a biocontrol agent used for biostimulation and against phytopathogens in agriculture. *Trichoderma harzianum* is used as a seed treatment, foliar application, and soil application for suppressing fungal pathogens (Pani *et al*., 2021). Applying *Trichoderma harzianum* to the soil has several benefits, including creating a barrier around the roots, improving soil health, and enhancing the availability of nutrients (Eman *et al.*, 2023). *Trichoderma* has been shown to promote plant growth in many ways. It has been used as a biofertilizer because it stimulates the plant growth of various crops. It can be used as an alternative to chemical fertilizers or as an amendment to improve crop production (Akladious & Abbas, 2014). *Trichoderma* strains produce asexual spores only, so they don't have a sexual stage. However, for very few strains, the sexual stage is known, but not in the strains used as biocontrol agents (Ghazanfar *et al*., 2018). Its efficacy is affected by both abiotic and biotic factors, and its efficacy is maximised by microencapsulation (Maruyama *et al*., 2020). It produces volatile compounds and plant growth hormones. It solubilizes phosphates that are unavailable to the plant. It promotes the uptake of micro- and macro-nutrients required by the crop (de Lima Gonilha *et al*., 2024).

Therefore, the study aimed at assessing how different soil amendments influence soil nematode populations as indicators of soil health. It also sought to determine whether these amendments improve the yield of common beans. Soil nematode populations were monitored to understand their role in soil and crop performance under different treatments. This study enhanced the identification and counting of free-living and plant-parasitic nematodes. Therefore, a study was carried out to evaluate the influence of the soil fertility management practices, growth, and yield of common beans on nematode communities in Tharaka Nithi County, Kenya.

1.2 Statement of the Problem

Common bean yield in Kenya is relatively low due to low soil fertility, pests and diseases, and unfavourable climatic conditions, among other factors. The total food demand is expected to double by 2030, and plant-parasitic nematodes have been reported to reduce yields. Plant-parasitic nematodes can result in yield losses of up to

60%. For instance, root-knot nematodes affect the nodulation of common beans. More research has been conducted on the impact of plant-parasitic nematodes on the yields of common beans; however, beneficial nematodes, such as free-living nematodes, have received relatively little attention. Free-living nematodes play a crucial role in the decomposition of organic matter and the recycling of nutrients. For instance, nematode fungivores and bacterivores do not feed directly on soil organic matter, but rather on fungi and bacteria that decompose organic matter. Scarce information is available on the influence of soil fertility management practices on soil nematodes. There is also scarce information on the abundance and diversity of plant-parasitic nematodes and free-living nematodes in Tharaka Nithi County.

1.3 Objectives

1.3.1 General Objective

To evaluate soil nematode communities as influenced by fertility management practices, growth and yield of common beans in Tharaka nithi, County.

1.3.2 Specific Objectives

i. To determine the effects of NPK (23.23.0), *Trichoderma harzianum*, and farmyard manure on numbers, evenness, and species diversity of soil nematodes under common beans

ii. To determine the effect of NPK (23.23.0), *Trichoderma harzianum*, and farmyard manure on common beans' growth and yield components.

iii. To determine the effect of NPK (23.23.0), *Trichoderma harzianum*, and farmyard manure on plant-parasitic nematodes in the roots of common beans.

1.4 Hypotheses

H_{01}: There is no statistically significant effect of NPK (23.23.0), *Trichoderma harzianum*, and farmyard manure on numbers, evenness, and species diversity of soil nematodes under common beans.

H_{02}: There is no statistically significant effect of NPK (23.23.0), *Trichoderma harzianum*, and farmyard manure on the growth and yield components of common beans.

H_{03}: There is no statistically significant effect of NPK (23.23.0), *Trichoderma harzianum*, and farmyard manure on plant-parasitic nematodes in the roots of common beans.

1.5 Justification

Common bean plays a vital role in human nutrition, although its production is affected by plant-parasitic nematodes, resulting in low yields. *Trichoderma harzianum* is a biocontrol agent for plant-parasitic nematodes, a growth-promoting agent in common beans, and a biofertilizer. It is an essential component for managing plant-parasitic nematodes, which are economically important (Maruyama *et al*., 2020). Free-living nematodes are beneficial and crucial to plant growth by decomposing organic matter and cycling nutrients in soil. They feed on living tissues, algae, fungi, bacteria, and dead organisms (Schratzberger *et al*., 2019). They improve the water-holding capacity and soil structure and release nutrients to plants. Nematodes serve as biological indicators because their community structure can indicate soil health (Marais *et al*., 2020). Farmyard manure and NPK (23.23.0) increase soil fertility once applied to the soil and hence will increase common bean yields. Inorganic fertilizers release nitrogen and phosphorus, encouraging nematode multiplication and plant growth (Pahalvi *et al*., 2021). The addition of farmyard manure leads to checked nematode populations because of competition for space and food with the soil organisms introduced. Due to adding organic matter, nematodes can react with manure amendments by increasing activity levels and numbers (Semenov *et al*., 2021). There is a need to grow common beans in Tharaka Nithi County for several reasons, including enhancing nutrition and food security, improving the livelihoods and income of farmers, improving soil fertility, and promoting agricultural sustainability (Lisciani *et al*., 2024). Farmers are advised on the appropriate strategies for managing plant-parasitic nematodes and promoting beneficial ones to enhance the yields of common beans and contribute to food and nutrition security.

CHAPTER TWO

LITERATURE REVIEW

2.1 Overview of Common Beans Production

Common beans, *Phaseolus vulgaris*, were domesticated in South America and Central Mexico 8000 years ago (Gaut, 2014). Ecuador and Peru were the centres of origin of common beans (Morales, 2006). India is the world's largest producer of beans. In 2021/2022, India produced 6,120,000 tonnes of dry common beans (Delfini *et al*., 2021). Tanzania is Africa's largest producer of common beans, producing 1.2 tons annually (Onyango, 2022). Common beans are widely cultivated in Kenya, especially for urban and rural diets. Common beans are mainly produced in Central, Western, Eastern, and Rift Valley regions (Duku *et al*., 2020). Despite their caloric intake, common beans are an essential source of protein and micronutrients (Nadeem *et al*., 2021). Common beans are appreciated widely because they are affordable and have a long storage life.

In Kenya, common beans are mainly intercropped with maize, cassava, coffee, millet, potatoes, and sorghum. The ecological requirements of common beans: soil pH of 6.5-7.5, altitude of 1000-2100m asl, rainfall of 800-2000mm, and temperature of 20-25℃; the soils should be well drained and not waterlogged (Porch *et al*., 2013). Constraints of common bean production are inadequate seeds, labour, diseases, pests, drought, and animal damage (Mangole *et al*., 2022). According to Mwaniki (2002), the unavailability of seeds limits the production of common beans. Most farmers use uncertified and of poor quality seeds; hence, there is a need to train farmers on quality seed production. Some pests affecting common beans in Kenya are plant-parasitic nematodes, aphids, armyworms, corn earworms, cutworms, leaf miners, loopers, Mexican bean beetles, stinkbugs, and spider mites (Singh & Schwartz, 2011).

Nematodes are free-living in soil, marine, and freshwater environments, but many species are parasitic, particularly on various animals and plants. The parasitic species have veterinary, clinical, and agricultural importance as parasites of livestock and man and pests of plants (Sánchez-Moreno & Ferris, 2018). Nematodes are found at the bottom of rivers, lakes, and huge depths, especially in oceans. Some nematode species can withstand temperatures consistently below the freezing point, while others thrive in hot springs. Nematode infestations at high initial population density result in significant yield losses. For instance, according to Adomako *et al*. (2022), yield losses may go up to 10%- 80%, especially with lesion nematodes, as well as 50%- 90% with root-knot nematodes (*Meloidogyne* spp.). Plant-parasitic nematodes, like the root-knot nematodes, predispose various crops to soil-borne microorganisms, which cause wilt diseases and root rot. Root-knot nematode infection also suppresses nodulation (Kimenju *et al*., 1999). Common beans are susceptible to various diseases caused by fungal oomycetes, bacteria, fungi, and viruses (Gupta & Singh, 2020).

2.2 Effects of NPK (23.23.0), *Trichoderma harzianum*, and Farmyard Manure on Numbers, Evenness, and Species Diversity of Soil Nematodes under Common Beans

2.2.1 Populations, Evenness, and Diversity of Soil Nematodes under Common Beans

According to Adomako *et al*. (2022), who conducted research to identify the occurrence of nematodes associated with common beans. Five genera were identified: *Trichodorus, Helicotylenchus, Meloidogyne, Rotylenchulus,* and *Pratylenchus. Meloidogyne spp* had the highest population density compared to *Trichodorus*. According to Li *et al.* (2020), we can determine that the diversity of soil nematodes at a high level of taxonomy (for example, order) can be a more suitable indicator compared to diversity at a low level of taxonomy (for example, genus and family). A study by Maina *et al*. (2022) showed a high abundance of plant-parasitic in pigeon pea cultivated as a monocrop, indicating that appropriate methods for nematode management should be implemented. A study conducted by Ye *et al*. (2019) showed that after testing for species diversity in a population of root-knot nematodes, five species of root-knot nematodes were identified, namely *Meloidogyne incognita, Meloidogyne hapla, Meloidogyne partityla, Meloidogyne marylandi,* and *Meloidogyne haplanaria*. *Meloidogyne incognita* was the most abundant species in 95% of the samples, particularly in field crops such as cotton and soybeans (Ye *et al*., 2019).

A survey conducted by Basavaraj *et al*. (2023) in India, following incidences of root-knot nematodes in common beans, found that the major symptoms include yellowing, root galls, root and tip rot, and marginal leaf drying. According to research (Indarti *et al*., 2023), three nematode PPN genera were identified: *Helicotylenchus spp.,* *Meloidogyne spp.*, and *Rotylenchulus spp. Rotylenchulus spp.* was the most common. The C/N ratio had a positive effect on the population of Meloidogyne spp., while total-N had a negative impact on the same species. It showed that the habitat conditions were homogeneous. A survey conducted by Krif *et al*. (2020) in Morocco aimed to determine the diversity and occurrence of PPNs in organically farmed fields. Twelve genera of PPNs were identified in root and soil samples. The most prevalent nematodes were root-lesion nematodes and root-knot nematodes. The bean crop exhibited high diversity indices of nematodes, particularly in terms of the plant-parasitic index, Shannon-Wiener index, and Evenness (Krif *et al*., 2020).

A study conducted by Nisa *et al*. (2021) assessed the effects of edaphic and ecological factors on the diversity of soil nematodes and their structures at five landscape patches from five different sites in India. Among the patches, forest soil had the highest diversity, while alpine soil had the lowest; however, bacterivorous organisms were observed to dominate in all soil patches (Nisa *et al*., 2021). An abundance of nematodes decreased from basic to acidic soil pH. Soil nutrients, such as phosphorus and nitrogen, were detrimental to nematode richness, particularly at every site, where nematode diversity was high in soils with abundant P and N but decreased with reduced soil nutrients (Lu *et al*., 2020). As noted by Xiao *et al*. (2021), nematode diversity and richness reach their peak in tropical ecosystems. Carnivores/Omnivores and bacterial feeders had the least relative abundance, but high diversity in the tropical ecosystem, with an opposite pattern evident for plant and fungal feeders. According to Atandi *et al*. (2022), it can be determined that organic farming systems play a vital role in population buildup and improving the biodiversity of free-living nematodes compared to other systems. Soil properties significantly impact plant-parasitic nematode communities, particularly in organic farming systems (Krif *et al*., 2020).

2.2.2 The Effect of Farmyard Manure, Chemical Fertilizer, and *Trichoderma harzianum* on Soil Nematodes under Common Beans

According to Termorshuizen *et al*. (2011), organic amendments enhance soil biological traits and suppress plant-parasitic nematodes. The major organic matter types used include composts, green manures, crop residues, agro-industrial waste, urban organic waste, animal manures, plant extracts, oil cakes, processing residues, and peats. Suppression involves either an indirect or a direct mechanism (Oka 2010). Direct mechanisms include reducing the population of phytonematodes by releasing nematistatic, nematicidal, or allelochemical compounds mostly from organic matter. Indirect mechanisms include increasing diversity and population of antagonistic microorganisms (Moosavi, 2022). When soil is organically amended, there is an increase in the population of phytonematodes when environmental conditions favor parasitic nematodes. Hence, exploring the potential function of organic amendments, such as cattle manure, controls parasitic nematodes (Maina *et al*., 2020). In the view of Atandi *et al*. (2017), who examined the comparison of various farming systems, organic farming, conventional farming, and farmer practice systems, and the differences in the suppression of PPNs in Kenya's maize and bean cropping systems. The study concluded that organic farming paradigms, especially those that employed the use of compost alongside Tithonia, remarkably helped reduce the abundance of Meloidogyne spp. and Pratylenchus spp. nematodes in soil. The management of root-knot nematodes using a bionematicide, such as Trichoderma harzianum, organic matter, and a soil fumigant has shown effective suppression of nematodes by limiting the application of chemicals (d'Errico *et al*., 2022).

A study by Puissant *et al*. (2021) conducted a global analysis of 103 publications to assess the impact of agricultural practices on nematodes, which are key indicators of soil health. The study quantified the impact of every agricultural practice change on nematode indices. Globally, nematicides and organo-mineral fertilization showed the highest effect sizes, while mineral fertilization had the least. As noted by Li *et al*. (2022), organic fertilization promotes fungal and bacterial feeders at the level of trophic groups. At the community level, nematicide application reduces the abundance of nematodes and alters the structure of the food web, thereby encouraging copiotrophic nematode communities. Control of plant-parasitic nematodes using a biological agent called *Trichoderma* has been widely studied. Yield losses and plant death resulted from the high population of plant-parasitic nematodes. According to Almeida *et al*. (2022), *Trichoderma harzianum* and *Trichoderma asperellum* were compared to suppress plant-parasitic nematodes. *Trichoderma harzianum* reduced the population of nematodes compared to *Trichoderma asperellum*, which did not even promote plant growth. 1, 3-dichloropropene, a fumigant, was combined with organic fertilizer and *Trichoderma harzianum* to investigate its effect on plant yield, growth, and root-knot nematode (d'Errico *et al*., 2022). Nematode infestation was reduced in all crops by all treatments, with the greatest nematicidal effect observed in the mixture of the three products. Fumigant integration with *Trichoderma harzianum* and organic fertilizer increased yield and crop growth.

Besides plant-parasitic nematodes, common beans are associated with free-living nematodes. In the view of Andrassy (2025), free-living nematodes form the highest population of nematodes, yet they are given little attention. Free-living nematodes occupy various trophic levels and are grouped according to their feeding habits. Some free-living nematodes include omnivores, bacterial feeders, predatory nematodes, and fungal feeders (Yeates *et al*., 1993). The roles of FLN are biocontrol of nematodes, organic matter decomposition, and nutrient mineralization; thus, they indicate the health status of the ecosystem (Ferris *et al*., 2012). Bacterial feeders consume bacteria and contribute 30-50% of nitrogen in plants (Ingham *et al*., 1985).

Fungal feeders puncture the cell wall of fungal hyphae using their stylet. Predatory nematodes consume invertebrates such as rotifers, protozoa, and other nematodes. Omnivores feed on fungi, plants, and invertebrates. Free-living nematodes (FLN) may accelerate soil organic matter decomposition. Numbers of FLN increase rapidly when inorganic fertilizers are applied, especially fungal and bacterial feeders (Maina *et al*., 2021). Plant-pathogenic nematodes have increased due to the increased application of potassium. Disease and pest control in amended soil is achieved by various mechanisms that operate via their effects on the pathogen, host plant, and soil. The mechanisms may include the accumulation of microbial metabolites, deleterious decomposition of end products, and increased tolerance and disease resistance (Hailu & Hailu, 2020).

2.2.3 Morphology of Nematodes

The morphology of nematodes is visible to us only after special procedures for extraction, as they are microscopic and require a microscope (Maggenti, 2020). These microscopes and procedures fully determine our facts of nematode morphology, because they limit the level at which we can study nematodes (Van *et al*., 2017). These procedures can result in substantial errors due to incorrect artifact interpretation, which they may create (Fourie *et al*., 2017). They are very small;

hence, the challenge is to identify and detect nematodes using a microscope (Eisenback & Hunt, 2009).

2.2.4 The body of the Nematodes

Soil nematodes have a body that is vermiform, tapering less or more strongly towards the posterior and anterior ends, and with no appendages capable of independent movement (Waggoner, 2020). The tail is the posterior end. The head is the anterior end, which is not offset from the body by a distinct neck; instead, it often blends smoothly into the body (Kiontke & Fitch, 2013). The anterior end is also referred to as the cephalic region, lip region, or simply the anterior end. The entire body is covered by a less or more impermeable, relatively tough and elastic cuticle (Fourie *et al*., 2017). The openings on the cuticle are for reproduction, "excretion," and digestion, as well as those of several secretory and/or sensory organs (Lazarova *et al*., 2021).

2.2.5 Hatching and Life Cycle of Nematodes

The life histories of many parasitic and free-living nematodes are quite similar in that they have four larval stages (Mkandawire *et al*., 2021). When the surroundings and temperature are unfavourable for the host, females of nematodes may not produce or produce few eggs (Wharton, 1986). Under less favourable conditions, such as extreme temperatures, a single female produces 300-500 eggs. However, in an optimum temperature of about 27 °C, more than 2800 eggs are produced (Luc *et al*., 1990). Eggs can be laid stuck together or singly in masses in a gelatinous matrix secreted by females (Lee, 2002). A new generation emerges in 25 days, but if conditions are less favorable, development may end completely, or the life cycle could be extended to 30-40 days. Nematodes' lifespans vary from a few days to many years. During the dormant stage, each egg typically has a thick outer covering that protects it during the inactive period (Kumar & Yadav, 2020). Plant-parasitic nematodes are elongated, fusiform, slender, circular in cross-section, and tapering towards both ends. In root-knot nematodes, eggs are laid in egg sacs that are mostly buried within the host-derived root galls, a characteristic of *Meloidogyne* spp. induce through feeding (Coulibaly *et al*., 2025).

Cysts and egg sacs protect eggs from natural enemies and desiccation. The juvenile in the egg matures into an adult by four moults. The first moult occurs in the egg. The egg develops into the first juvenile stage (J1) (Luc *et al*., 1990). Juvenile coils numerous times within the eggshell and lies still. The J1 grows through the egg's first moult, then hatches as J2 (Fourie *et al*., 2017). J2 is small in size, lacks organs of reproduction, and is fully developed. J2 undergoes a second moult and develops into J3, then a third moult to become J4 (Hooper *et al*., 2005). The J4 stage goes through the fourth moult, and differentiation occurs, developing into adult males and females, which then mature. Temperature is important for the life cycle of nematodes, as illustrated by Agrios (2005). A life cycle from egg to adult can be completed in 3 to 4 weeks under optimal environmental conditions, such as 27℃ and a soil pH of 4.0–8.0. The life cycle of *Ditylenchus dipsaci* takes 19- 23 days, whereas *Longidorus* spp. takes two years (Fourie *et al*., 2017). Second-stage juveniles penetrate plants at a temperature between 10℃ and 35℃, with 27℃ being the optimum temperature, depending on the species.

In various nematode species, the life cycle of the nematodes is closely synchronized with that of the host, facilitated by host- and environment-derived stimuli, to enhance nematode reproduction (Kumar & Yadav, 2020). Each egg has a single juvenile, which hatches through cutting the eggshell with its stylet, through striking it with rhythmic blows that are intermittent or egg-shell rupturing with the tip of the tail, like in *Heterodera iri*, or by normal egg-shell rupture because of secretions of juvenile enzymes and movement (Mkandawire *et al*., 2021). Eggs of cyst nematodes either survive in lemon-shaped (*Heterodera*) or round (*Globodera*) cysts in the soil, each with hundreds of eggs. Cysts have tiny openings at the vulval ends and neck where hatched juveniles can escape (Fourie *et al*., 2017).

Once they hatch, the J2s of *Globodera pallida* and *Globodera rostochiensis* have a short survival span of less than two weeks without feeding, in comparison to *Tylenchulus semipenetrans* and *Meloidogyne javanica,* which can survive in the field for several months (Perry & Clarke, 1981). The occurrence of plant-parasitic nematodes has been reported to show a close association with leguminous crops, including common beans, as highlighted by Kimenju et al. (1999). Several nematode groups are commonly linked to beans: lesion nematodes such as *Aphelenchus spp.,* *Pratylenchus spp.*, *Criconemella spp.*, and *Tylenchus spp*.; root-knot nematodes (*Meloidogyne spp*.); stubby root nematodes (*Trichodorus spp*.); sheath nematodes (*Hemicycliophora spp*.); and other nematodes are associated with beans. *Meloidogyne* spp. are the most important because they are widely distributed, primarily in warm areas of the world, and exhibit a polyphagous nature (Coulibaly *et al*., 2025).

2.3 The Effects of NPK (23.23.0), *Trichoderma harzianum*, and Farmyard Manure on Common Bean Growth and Yield Components.

A study by Tadesse & Abera (2023) found that applying farmyard manure increased yield components and the yield of haricot bean. Parameters like plant height, flowering, maturity, seed weight, and number of branches were influenced by farmyard manure. Research by Singh *et al*. (2022) found that integrating bio fertilizer and farmyard manure with 60 $kgha^{-1}$ single super-phosphate improved the yield of black gram by 3.28% and 7.4% respectively, compared to using 60 $kgha^{-1}$ single super-phosphate alone. Uptake of phosphorus in black gram when biofertilizer and FYM were applied together with single superphosphate showed improvement of uptake compared to 60$kgha^{-1}$ single superphosphate. According to the research by Shadrack *et al*. (2021), a study was conducted where Diammonium phosphate (0 and 62.5 $kgha^{-1}$), Mavuno (0 and 185 $kgha^{-1}$), lime (0 and 1.6 or 2.0 tha^{-1}), and Sympal (0 and 125 $kgha^{-1}$) were applied under common beans. Applying lime and Mavuno increased common bean grain yields compared to the Sympal, control, and Diammonium phosphate. According to Raihan *et al*. (2021), farmyard manure contributed significantly to high seed germination rates, maximum bean height, accelerated first flowering days, increased number of pods per plant, maximum pod length of individual plants, pod weight, and pod width. Farmyard manure influenced the yield component and plant growth of the country bean.

A study by El-Yazal (2020) treated broad beans with different rates of minerals (NPK) and organic manure (farmyard). The plants that were organically fertilized attained higher values of various growth parameters (number of branches, plant height, dry weight, and plant leaflets' blade area) and yields, as well as broad bean components (number of pods/seeds, weight of pod/ seeds, number of plants/ pods, and weight of plant/seeds). According to the research (Nigatie, 2021), it can be determined that P and N fertilizers have a significant impact on common bean production. Increasing nitrogen rates resulted in increased grain yields in two cultivars. The Dume variety showed great performance, followed by Nasir, while Ibbado indicated the least expectation. Research by Naluzze (2022) evaluated the effect of manure and NPK fertilizer on yield components of common beans. The inorganic fertilizer used was NPK 17:17:17; the results showed no significant effect on the growth parameters. Research conducted by Zamukulu *et al*. (2023) in eastern Democratic Republic of Congo determined that NPK fertilizer increased grain yield. It was evident in plants with high plant density compared to plants with low plant density. The study by Atandi *et al*. (2017) showed that organic farming paradigms, especially those that employed the use of compost alongside Tithonia, remarkably helped boost the growth of beans and elevate soil health.

Research conducted by Upenji (2020) over two seasons found that manure was applied at rates of 0 and 5 tons/ha. The seed yield of bean varieties significantly fluctuated according to manure input, variety, and season. The second season was more productive than the first season. The application of manure appeared to be the primary option for improving the seed yield of beans, thereby ensuring food security. According to Obsa (2017), it can be determined that the highest biomass and grain yield were achieved by applying the recommended P-fertilizer compared to vermicomposting material. Combining P-fertilizer and vermicomposting material increased yield compared to P-fertilizer alone, which can be considered an alternative for mostly integrated inorganic and organic nutrient sources for crop productivity and soil health. Plants fertilized with farmyard manure had higher values of Chlorophyll concentration, total amino acids, carotenoids, total carbohydrates, crude proteins, total sugars, insoluble carbohydrates, and reducing sugars in seeds and leaves compared to plants fertilized with NPK (El-Yazal, 2020).

A study by Ali *et al*. (2023) where NPK and organic fertilizers at a rate of 600 kg ha-1 were applied to common beans. Organic fertilizers increased growth parameters (plant height and number of branches), yield components (number of seeds, grain yield, and number of pods), and dry matter compared to the control in common beans. According to Zongo *et al*. (2024), who determined the effects of applying organic compost and Trichoderma harzianum on the growth of soybeans and soil fertility. The analysis revealed that the application of organic compost mixed with Trichoderma increased soil fertility by enhancing the presence of nitrogen (N), phosphorus (P), and potassium (K), which are vital in catalysing plant growth. Together, these practices demonstrated improved plant growth and nodulation, indicating that organic amendments and biocontrol agents can enhance nutrient availability and reduce the population of nematodes in the legume system (Zongo *et al*., 2024).

The benefits of *Trichoderma* species include promoting growth, enhancing seed viability and germination, increasing flowering, photosynthesis, and yield, as well as improving root condition and structure (Tyskiewicz et al., 2022). Mahmoodian *et al*. (2022) reported that different *Trichoderma harzianum* species have been used mostly as antagonists against various plant diseases. A direct relationship exists between fungi, biocontrol potential, and the rate at which enzymes degrade pathogens' cell walls. Chimeric chitinase 42 has been produced through protein engineering in various works by the author; the resultant protein was then transferred to *Trichoderma harzianum.* The research stability and presence of chimeric Chitinase were evident when the biocontrol potential and growth stimulation of six isolates were evaluated on common bean plants in greenhouse and laboratory conditions, compared to the wild type (Mahmoodian *et al.*, 2022). Seven *Trichoderma* species demonstrated increased shoot weight, root length, and shoot length in green gram (Mukhtar *et al*., 2021).

Research by Elkelany *et al*. (2021) reported that three species of *Trichoderma*, *Trichoderma virens*, *Trichoderma viride,* and *Trichoderm*a *harzianum,* improved the growth and yield of peanuts. The results were demonstrated by the dry and fresh weights of peanut plants, the weight of pods, and the number of pods. According to El-Nagdi *et al*. (2019), we can determine that after the application of *Trichoderma harzianum* in the soil, the growth and yield of pea also increased, which was demonstrated by the pod's dry weight, root fresh and dry weight, and shoot length. According to the research (Yao *et al*., 2023), Trichoderma prevents diseases in plants, improves the utilisation of nutrients, and promotes growth. According to Olabiyi *et al*. (2016), we can determine that Trichoderma harzianum contributes to the effective growth of crops and a reduction in damage caused by nematodes.

2.4 Effect of NPK (23.23.0), *Trichoderma harzianum*, and Farmyard Manure on Plant-parasitic Nematodes in the Roots of Common Beans.

2.4.1 Nematode pathology

Plant-parasitic nematodes are biotrophic parasites; they obtain nutrients from the leaf cells, stem, and cytoplasm of living roots for growth, development, and survival. Nematodes have developed diverse feeding relationships and parasitic strategies with their plant hosts (Afzal & Mukhtar, 2024). They possess protrusible and hollow feeding structures, pharynxes, and stylets, and have undergone physiological and morphological adaptations to suit their feeding relationships (Eves-van den Akker, 2021). Depending on the species, they can feed on the cytoplasm of living plant cells that are either unmodified or have undergone modification to develop into elaborate feeding cells, as seen in root knot nematodes (Perry & Moens, 2011). The stylet of the nematode is used to penetrate and pierce the cell wall of the plant cell. Gland secretions are injected via the stylet orifice into the cell, where they are withdrawn as well as ingested by the nematode from the cytoplasm.

The stylet is also used by nematodes that enter the root tissue through openings or inject secretions to weaken or dissolve the middle lamella or cell wall (Arley Rey Páez, 2023). In general, all plant-parasitic nematodes damage plants through direct mechanical injury by use of the stylet in secretion and/or penetration of enzymes in the cells when the parasitic nematode is feeding (Bird & Bird, 2012). The physical presence of endoparasitic nematodes within the host typically disrupts the normal functioning of that host. However, the nematode architecture, feeding, and root system extent have changed, as it takes up water and nutrients from the soil less efficiently (Lee, 2002). The damage caused by nematodes depends on the inoculum density, that is, the infestation level. Moderate or low nematode numbers may result in more injury, but extremely high numbers can severely kill or damage their host.

2.4.2 Classification of Root-Knot Nematodes, *Meloidogyne* spp.

Root-knot nematodes belong to the kingdom; *Animalia*, phylum; *Nematoda*, class; *Nemata*, subclass; *Sercenentea*, order; *Tylnchida*, suborder; *Tylenchina*, family; *Meloidogynidae*, and genus; *Meloidogyne* (Perry *et al*., 2009). There are 51 *Meloidogyne* species, of which M. hapla, M. arenaria, M. javanica, and M. incognita are economically significant in the production of beans worldwide (Churamani, 2017). Populations of root-knot nematodes consist of females and males, which are distinguished morphologically. Males are like worms and are 1.20- 1.50 mm long and have a diameter of 30- 60µm (body width) (Meza *et al*., 2016). Female adults are pear-shaped and are 0.40 - 1.30 mm long by 0.27 - 0.75 mm in width. Second-stage juveniles have a vermiform shape, whereas third as well as fourth-stage juveniles are microscopic in size and sausage-shaped (Perry *et al*., 2009).

2.4.3 Effect of Plant-parasitic Nematodes on Nodulation of Bean Roots

Plant-parasitic nematodes disrupt the process of nodulation in common beans by directly damaging the root tissues and indirectly affecting the symbiotic relationship with rhizobia (Kimenju *et al*., 1999). Plant-parasitic Nematodes create a feeding site inside the nodule in the vascular bundle and encourage the development of giant cells that disrupt the function of the nodules. This results in nodules having premature senescence, hence a reduced ability to fix nitrogen (Kimenju *et al*., 1999). They also affect nodulation by competing for nutrients and ecological niches, as well as suppressing the formation of lateral roots, thereby reducing the number of nodule formation sites. This results in the early degradation of nodules due to infection (Faridah & Van der Maesen, 1997). According to the research by Zongo *et al*. (2024), the application of Trichoderma harzianum resulted in improved nodulation in soybeans.

CHAPTER THREE
MATERIALS AND METHODS

3.1 Location of Study

The study was conducted in Karingani Ward, Chuka Sub-County, Tharaka Nithi County. The experiment was carried out from April 2024 to October 2024. The study site was located at a latitude of 00°18'37'' South and a longitude of 037° 39'38.0'' East, approximately 1324 m above sea level (asl). The mean temperature is about 20 °C. The county has a bimodal rainfall pattern, with the long rains falling from April to June and the short rains from October to December. On average, the area receives about 1200 mm of rainfall annually. The soils in this area are Nitisols, characterized as deep, well-drained, strongly weathered, with moderate to high fertility, and possessing good water-holding capacity (Jaetold *et al*., 2006). The climatic conditions are favourable for common bean farming. The economic activities in this area are agriculture, commerce, and trade. Agriculture is primarily an economic activity in this area, where various crops are supported by the region's agro-ecological zones, including cash crops (such as coffee and tea) and food crops (beans, maize, millet, and green grams). Dairy farming is also widely practiced, contributing significantly to household incomes.

3.2 Research Design and Treatments

The experimental design was a randomised complete block design (RCBD) with four treatments and three replications. The four treatments were: NPK (23.23.0) at 125 kg/ha, farmyard manure at 10 ton/ha as recommended by KARLO, *Trichoderma harzianum* (45g/20 l) as recommended by the manufacturer, and a control was assigned to three blocks. The plot size was 1.8 m by 1.5 m with a spacing of 0.45 m by 0.15 m, translating to 148,149 plants per hectare and 40 plants per plot. The spacing between plots was 1m. The experiment was conducted in two trials, each with a similar layout.

The layout was as follows:

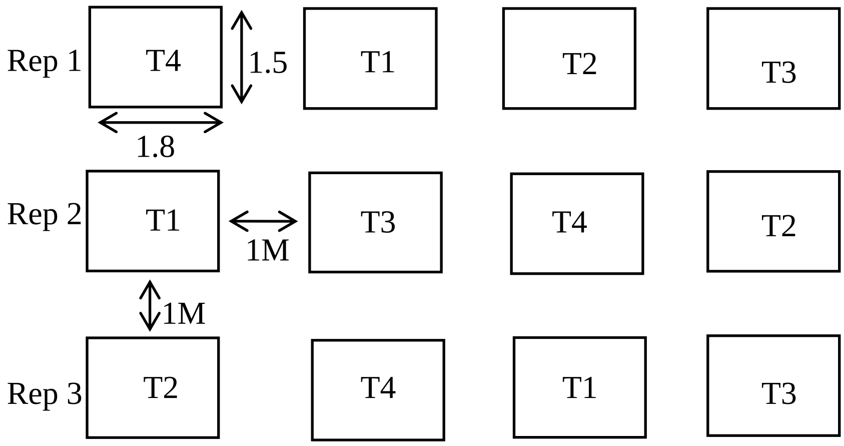

Figure 1: Farm Layout

Legend: T1-Control; T2-NPK (23.23.0) at 125 kg/ha; T3-farmyard manure at 10 tons/ha; T4-*Trichoderma harzianum*; Rep- Replicate

3.3 Crop Establishment and Management

Land preparation; the land was prepared by clearing previous crop residues and removing stumps and other foreign materials. Ploughing was done to a fine tilth, soil clods were broken, and land planning was considered, taking into account the type of irrigation used. The experimental field layout was done as per the above specifications. Planting; common bean seeds were sown in rows at a spacing of 0.45 x 0.15 m at two seeds per hill to a depth of 1cm, and requisite treatments applied per plot at sowing. Certified common beans were obtained from KALRO. Weeding; regular control of weeds was maintained to prevent competition for nutrients, water, space, and sunlight. Weed control was done manually by uprooting and using a panga. The appropriate method was uprooting because there was no damage to the roots. Weeds can harbour pests and diseases; therefore, weeding was done appropriately. Common pests and diseases were managed appropriately. Confidor WG 70 was drenched into the soil at a rate of 5g per 10 litres, as recommended by the manufacturer, to prevent cutworms from cutting germinating seedlings. Thinning; thinning was done two weeks after seedling emergence, at the four-leaf stage, when dried and weak seedlings were replaced. Irrigation; irrigation was done within the experimental site using a watering can. This method is good due to its water use efficiency and small area of operation. The amount of water applied per plot was 40 litres. The irrigation was done in the evening as needed.

3.4 Sampling Procedures

3.4.1 Soil Sampling Procedure

The soil samples were taken from the field prior to sowing, at the flowering stage, and after harvesting the common beans in each trial. The soil sampling pattern was zig-zag to a depth of 25 cm with a soil auger at 4 points per plot. A composite sample of 300g was taken from each plot, packed in a zip bag, and stored in a cool box for nematode analysis in the lab.

3.4.2 Laboratory Procedure for Nematode Isolation (Modified Baermann Technique)

As described in Van (2006) nematode extraction, counting, and identification were carried out at the ICIPE Nematology laboratory. The Baermann technique was used to extract nematodes from the soil and roots. The procedure of nematode extraction from the soil was done as follows. 100 ml of soil was placed on the cotton-wool milk filter, which was held by support; maximum soil layer thickness was 2-3 mm. Support was placed with a sample into the funnel. Water was added from the side until the sieve's bottom touched the water. Nematodes left the soil, passed through the cotton-wool milk filter, and sank to the funnel's dish. Nematodes were collected after 48hours in Falcon tubes of 50 mL. Nematodes were allowed to settle on the Falcon tubes of 50 mL; supernatant was removed, passed through 25-micrometre sieves to reduce water volume. Nematodes were counted using a dissecting microscope at a magnification of 25-40x and identified using a compound microscope at a magnification of 10- 100x within a counting slide with a 2ml sample. Nematodes were identified to the genus level using an identification key and descriptions by Mai (2018)

3.4.3 Extraction of Nematodes from Common Bean Roots (Modified Baermann Technique)

Nematode extraction was done as described in Van (2006). Materials: knife, pair of scissors, cotton-wool milk filter, glass funnel with a piece of soft polyethene tube attached to the stem and closed with a screw clip, stand, support, 20 or 25µm sieve, 100ml glass beaker, dissecting microscope, and counting slide. Roots were chopped into ±1 cm pieces. 5g of roots were weighed using a weighing balance. Roots were placed on a cotton-wool milk filter placed within a support (sieve). Support with the sample was submerged gently in the water in the funnel. Nematodes were collected after 48 hours by opening the screw clip on the funnel stem. Nematodes were allowed to settle in the falcon tubes, and the suspension was passed over a 25 µm sieve to reduce the volume of water. Nematodes were counted using a dissecting microscope at a magnification of 25-40x and identified using a compound microscope at a magnification of 10- 100x within a counting slide with a 2ml sample. Nematodes were identified to the genus level using an identification key and descriptions by Mai (2018).

3.5 Data Collection

Data collection was done on common bean growth and yield components: height, number of leaves, number of branches (from the four middle tagged plants), emergence, biomass, number of pods, number of seeds, nodules, and grain yields. In contrast, nematode numbers were counted, and species diversity and evenness were calculated per plot. Data were collected under the following objectives.

3.5.1 To Determine the Effects of NPK (23.23.0), *Trichoderma harzianum*, and Farmyard Manure on Numbers, Evenness, and Species Diversity of Soil Nematodes under Common Beans.

Nematode species were identified up to the genus level and counted after carrying out the Baermann Technique in the laboratory (as described in 3.4.2).

Shannon Diversity Index (Konopinski, 2020)

$H' = -\sum [(pi) \times \ln (pi)]$

H′- Shannon diversity index

*p*i- proportion of individuals of a nematode species in a whole community

∑- sum symbol

In- usually the natural logarithm (base e ≈, 2.718)

Simpson's Index of Diversity (Kim et al., 2017)

$$D = 1 - \left(\frac{\sum n(n-1)}{N(N-1)}\right)$$

n- the total number of organisms of a particular nematode species

N- the total number of individual nematode species (all species combined)

The value D ranges from 0 to 1

Species Evenness (Mulder *et al.*, 2004)

$$EH = \frac{H'}{In(s)}$$

H′- Shannon diversity index

S- Total number of nematode species

In- Natural log

The value EH ranges from 0 to 1

3.5.2 To Determine the Effect of NPK (23.23.0), Trichoderma harzianum, and Farmyard Manure on Common Beans' Growth and Yield Components.

Common beans emergence; this was calculated as a percentage as the number of emerged seeds divided by the number of planted seeds multiplied by 100. Height; a ruler was used to measure the plant height from the base of the stem to the top of the canopy (this was the tip of the apical bud). It was done every two weeks and recorded in cm. Number of leaves; unfolded leaves of common beans were counted after every two weeks after sowing. All leaves were counted from the bottom of the crop. Number of branches; branches of common beans were counted after every two weeks after sowing. Branches were counted from the bottom of the crop. Biomass; destructive harvesting was done after maturity of common beans, where the plants were weighed after removing seeds from the pods using a weighing balance and recorded in kg. The samples were placed in an oven at 60℃ for 48 hours in the Chuka University Plant Sciences laboratory. Dry biomass was weighed using a weighing balance and recorded in kg. Yield and yield components assessment; ten plants were randomly selected from each plot and tagged at pod maturity. Pods were harvested and placed in zip bags. The harvested pods from the sampled plants were shelled, and seeds counted for each plant. The average numbers of seeds per plant/plot were obtained. The final grain yield was determined by weighing all the seeds from the sampled plants and converting the yield to kilograms per hectare.

3.5.3 To Determine the Effect of NPK (23.23.0), *Trichoderma harzianum*, and Farmyard Manure on Plant-Parasitic Nematodes in the Roots of Common Beans

Root samples were taken from all plots with different treatments, i.e, NPK (23.23.0), farmyard manure, *Trichoderma harzianum,* and control. Nematode species were identified up to the genus level and counted after carrying out the modified Baermann Technique (as described in 3.4.3). Nodules; three plants were randomly selected from each plot and carefully dug out at the 70% flowering stage (45 days) after emergence. The plants were separated into shoots and roots. The roots were dipped in a bucket of water to remove the soil. The roots with undisturbed nodules were labelled in zip bags and then taken to the laboratory. Nodules were manually removed from the roots, and their numbers were recorded for each plant.

3.6 Data Analysis

Collected data on bean growth and yields were subjected to analysis of variance (ANOVA) using R version 4.5.1, and significant means were separated by LSD at $\alpha=0.05$. Species diversity was determined using Shannon and Simpson's indices, while evenness was calculated using Pielou's index on different treatments. The statistical model used is as follows:

$Y_{ij} = \mu + \tau_i + \beta_j + \epsilon_{ij}$

Y_{ij}: observed response (e.g plant height, biomass, number of leaves, seeds, pods, and branches) of the i^{th} treatment in the j^{th} replicate (block).

μ: this is the overall mean of all observations

τ_i: Effect of the i^{th} treatment where i=1,2,3,4

τ_1 - effect of control

τ_2- effect of NPK 23.23.0

τ_3- Effect of farmyard manure

τ_4- effect of *Trichoderma harzianum*

β_j: effect of j^{th} block where j=1,2,3

ϵ_{ij}: random error term, assumed to be independently and normally distributed with mean 0 and constant variance.

3.7 Ethical Consideration

The Chuka University Institutional Ethics Review Committee requirements were followed keenly, ensuring confidentiality and security of collected data. An ethical clearance letter was acquired from Chuka University (Appendix 78). A permit was obtained from the National Commission for Science, Technology and Innovation (NACOSTI) after the proposal had been reviewed and approved (Appendix 79). All the collected data were used solely for academic purposes without reference to individuals.

CHAPTER FOUR

RESULTS AND DISCUSSION

4.1 Effects of NPK (23.23.0), *Trichoderma harzianum*, and Farmyard Manure on Numbers, Evenness, and Species Diversity of Soil Nematodes under Common Beans

4.1.1 Free-living Nematodes Identified in Soil

Table 1 presents the results from trials one and two, which determine the effect of different treatments (farmyard manure, Trichoderma harzianum, NPK, and control) on FLN populations at various growth stages of common beans (initial, flowering, and final). The FLN identified included predators, bacterivores, and *Aphelenchus spp*, *Dorylaimus spp*, and *Aphelenchoides* spp, and the total nematodes present (100ml soil sample).

Table 1: Free-living Nematodes Identified (100ml of soil) in NPK, FYM, and *Trichoderma harzianum* under Common Beans

Trial	Stage	TRT	Bacterivores	Predator	*Aphelenchus spp*	*Aphelenchoides spp*	*Dorylaimus spp*	total
1	Initial	Control	200	65	280	13	57	615
		NPK	107	97	144	30	81	459
		FYM	100	5	106	0	12	223
		TH	84	50	80	0	5	219
	Flowering	Control	100	6	138	0	33	277
		NPK	87	0	78	23	0	188
		FYM	167	11	123	0	15	316
		TH	92	68	145	0	22	327
	Final	Control	75	4	77	0	0	156
		NPK	63	0	60	10	0	133
		FYM	206	15	200	0	35	456
		TH	100	80	196	5	25	406
2	Initial	Control	75	4	77	0	0	156
		NPK	63	0	60	10	0	133
		FYM	206	15	200	0	35	456
		TH	100	80	196	5	25	406
	Flowering	Control	17	8	30	8	0	63
		NPK	26	0	60	15	0	101
		FYM	584	0	162	0	85	831
		TH	82	45	227	0	58	412
	Final	Control	10	13	40	0	0	63
		NPK	104	23	105	60	25	317
		FYM	983	34	312	0	97	1426
		TH	163	100	312	100	70	745

Legend: TRT- Treatment; TH- *Trichoderma harzianum*; FYM- Farmyard manure; Initial- nematodes identified before applying treatments; Flowering- nematodes identified at flowering stage of common beans; Final- nematodes identified after harvesting common beans. *Aphelenchus spp*- fungal feeder; *Aphelenchoides spp*- fungal feeder; *Dorylaimus spp*- omnivores (some are fungal feeders).

Table 2: Effect of NPK, FYM, and *Trichoderma harzianum* on Free-living Nematodes under Common Beans

TRIAL	STAGE	TREATMENT	FLN IN SOIL
1	Initial	Control	615[a]
		NPK	459[ab]
		FYM	223[b]
		TH	219[b]
	Flowering	Control	277[ab]
		NPK	188[b]
		FYM	316[b]
		TH	327[a]
	Final	Control	156[b]
		NPK	133[b]
		FYM	456[a]
		TH	406[a]
2	Initial	Control	156[b]
		NPK	133[b]
		FYM	456[a]
		TH	406[a]
	Flowering	Control	63[c]
		NPK	101[bc]
		FYM	831[a]
		TH	431[b]
	Final	Control	63[c]
		NPK	317[c]
		FYM	1426[a]
		TH	745[b]
		Means	370.75
		CV (%)	25.47
		$LSD_{(0.05)}$	183.25

Legend**:** CV- Coefficient of Variance; TH- *Trichoderma harzianum*; FYM- Farmyard manure; Initial- nematodes identified before applying treatments; Flowering- nematodes identified at flowering stage of common beans; Final- nematodes identified after harvesting common beans. *Means with the same letters within the column are not significantly different at (P <0.05).*

As shown in Table 2 for trial one, at the initial stage, the control had the highest population of free-living nematodes (615), which was significantly different (p < *0.05)* (Appendix 2) from TH (219) and FYM (223). At this stage, no treatment had been applied. At the flowering stage, TH (327) was significantly different *(p<0.05)* (Appendix 3) from NPK (188) and FYM (316). Control treatment (277) was not significantly different *(p>0.05)* from FYM, TH, and NPK. At this stage, FLN had begun to show improved decomposition of organic matter, while TH exhibited microbial interactions, which provided conducive conditions for FLN to thrive. At the final stage, TH (406) and FYM (456) were significantly different *(p<0.05)* (Appendix 4) from NPK (133) and control (156), but there was no significant difference between TH and FYM. The difference between control, NPK, and organic treatments indicates the availability of organic matter from FYM and TH, which supported FLN. Farmyard manure had the highest population of FLN, followed by TH, while control and NPK reduced FLN in both trials. Farmyard manure increased free-living nematodes because it has decomposable and organic matter, which stimulates the growth of FLN. *Trichoderma harzianum* is a fungus that suppresses PPNs but also encourages microbial biomass and diversity. This provides food sources and a favourable environment for free-living nematodes. Control treatment reduced FLN because natural resources were depleted.

In trial two, at the initial stage, TH (406) and FYM (456) were significantly different *($p<0.05$)* (Appendix 5) from NPK (133) and control (156), but there was no significant difference ($p>0.05$) between TH and FYM. At the flowering stage, there was a notable increase where FYM (831) was significantly different *($p< 0.05$)* (Appendix 6) from TH (431), NPK (101), and also Control (63). NPK and control were statistically similar. The results showed that FYM had a superior ability compared to TH, especially during the peak growth stage for common beans in supporting FLN. At the final stage, there were pronounced differences where FYM (1426) was significantly different *($p< 0.05$)* (Appendix 7) from TH (745), NPK (317), and also Control (63).

Tables 1 and 2 show significant variations in free-living nematode population (FLN) across different treatments and bean growth stages. In trial two, farmyard manure (FYM) treatment demonstrated the highest nematode population, especially in the final stage, 456 (initial), 831 (flowering), 1426 (final), compared to the control, which had 156 (initial), 63 (flowering), and 63 (final). Application of FYM significantly enhances soil fertility and FLN biodiversity in common beans. This shows that organic amendments, such as FYM, provide conditions that favour nematode proliferation due to increased nutrient availability and microbial activity. In both trials and all stages of growth, FYM resulted in the highest populations of bacterivores, predators, *Aphelenchus spp,* and *Dorylaimus spp* nematodes compared to the control treatment especially in trial two. For instance in trial 1 FYM increased bacterivores from 100 (initial) to 167 (flowering) to 206 (final), predator from 5 (initial) to 11 (flowering) to 15 (final), *Aphelenchus* spp from 106 (initial) to 123 (flowering) to 200 (final) and *Dorylaimus* spp from 12 (initial) to 15 (flowering) to 35 (final). In comparison to control in trial one which reduced bacterivores from 200 (initial) to100 (flowering) to 75 (final), predator from 65 (initial) to 6 (flowering) to 4 (final), *Aphelenchus* spp from 280 (initial) to 138 (flowering) to 77 (final), *Aphelechoides* spp from 13 (initial) to 0 (flowering) to 0 (final) and *Dorylaimus* spp from 57 (initial) to 33 (flowering) to 0 (final).

These findings are in line with those of Yeates *et al*. (1993), who reported that organic amendments enhance the abundance and diversity of soil nematodes. This is evident in the final and flowering stages, where nematode numbers are elevated in comparison to other treatments. For instance, in trial two at the final stage, farmyard manure recorded 983 bacterivores. A High population of Bacterivores was attributed to organic matter decomposition in FYM, which is consistent with the findings of Ferris *et al*. (2001), who reported that organic amendments promote bacterivores nematodes. These findings compare to those of Atandi *et al*. (2022), who found that bacterial feeder nematodes were dominant FLN in systems that were organically managed compared to control and conventional systems. The presence of predator nematodes indicated a balanced soil ecosystem.

Predator nematodes contribute to the suppression of plant-parasitic nematodes and other soil organisms that can affect the yield of common beans. These findings corroborate with those of Kimenju *et al*. (2009), who reported that application of organic amendments suppresses PPNs by promoting beneficial microbial interactions. *Aphelenchus spp* are fungal feeders. When FYM is added to the soil, it results in increased fungal biomass since there is decomposition of organic matter. These fungal feeder nematodes play a key role in nutrient cycling and are an indicator of fungal activity in the rhizosphere of common beans. *Dorylaimus* spp have diverse feeding habits and act as omnivores. FYM resulted in a diverse microbial community, which provided a suitable environment for *Dorylaimus spp*. These findings comply with those of Hu *et al*. (2018), who reported that a high population of *Dorylaimus spp*, *Aphelenchus spp*, and predator nematodes was due to soil health and food resources in organically amended soil.

Trichoderma harzianum increased free-living nematodes in both trials, but trial two had the highest population. *Trichoderma harzianum* treatment increased progressively the populations of free-living nematodes from the initial to final stage, that is, bacterivores, predators, *Aphelenchus spp*, *Aphelenchoides spp,* and *Dorylaimus spp,* indicating a suppressive effect of biocontrol agents on plant-parasitic nematodes compared to control. For instance in trial two *Trichoderma harzianum* increased bacterivores from 100 (initial) to 82 (flowering) to 163 (final), predator from 80 (initial) to 45 (flowering) to 100 (final), *Aphelenchus spp* from 196 (initial) to 227 (flowering) to 312 (final), *Aphelenchoides spp* from 5 (initial) to 0 (flowering) to 100 (final) and *Dorylaimus spp* from 25 (initial) to 58 (flowering) to 70 (final) while control reduced bacterivores from 75 (initial) to 17 (flowering) to 10 (final), *Aphelenchus spp* from 77 (initial) to 30 (flowering) to 40 (final), *Aphelenchoides spp* from 0 (initial) to 8 (flowering) to 0 (final) and *Dorylaimus spp* from 0 (initial) to 25 (flowering) to 0 (final).

These results showed the role of TH in organic matter decomposition and soil microbial activity. *Trichoderma harzianum* is a fungus that colonizes soil organic residues, secretes extracellular enzymes, and accelerates the breakdown of organic substrates. This process releases nutrients and stimulates the proliferation of soil bacteria and fungi, which in turn provide abundant food resources for bacterivorous and fungivorous nematodes. Furthermore, *T. harzianum* contributes to improved soil biological quality by increasing microbial biomass, promoting nutrient mineralization, and enhancing soil enzyme activity. These processes enrich the soil food web and create favorable microhabitats that support a higher abundance of FLN. These findings corroborate with those of Sharon *et al*. (2011), who reported that *Trichoderma spp*. can suppress plant-parasitic nematodes (PPNs) through competition for resources and enzymatic degradation. The nematode population observed was consistent with these findings, showing its potential role in the management of parasitic nematodes.

These findings are consistent with those of Giada d’Errico *et al*. (2022), who investigated the combined application of *T. harzianum*, the fumigant 1,3-dichloropropene, and organic fertilizer on tomato crops infested with *Meloidogyne incognita*. The integrated treatment not only significantly reduced nematode infestation but also enhanced plant growth and yield, suggesting that *T. harzianum* contributes to nematode suppression and promotes beneficial soil microbial communities. There was an increase in bacterivores, which are bacterial feeder nematodes. This increase resulted from *Trichoderma harzianum,* which enhanced soil microbial communities, hence promoting the abundance of bacterial feeder nematodes. *Aphelenchus spp* and *Aphelenchoides* spp increased because of an increase in fungal biomass in the soil after the application of *Trichoderma harzianum*. *Trichoderma harzianum* is also a fungus, and it has been shown to have altered the fungal community in favour of *Aphelenchoides spp.* and *Aphelenchus spp*. The findings are in line with those of Pinto *et al*. (2024), who reported that *Trichoderma spp*. not only protects plant roots from PPNs, but also influences fungal nematodes, which can make *Trichoderma* less effective in managing plant-parasitic nematodes. The effect of *Trichoderma harzianum* on *Dorylaimus spp.* varies. It showed a slight increase compared to the control treatment.

In comparison, control and NPK treatments had lower FLN populations compared to *Trichoderma harzianum* and FYM across all stages in both trials. For instance, in trial one NPK treatment resulted to reduced population of predator from 97 (initial) to 0 (flowering) to 0 (final), fungivorous; *Aphelenchus spp* from 144 (initial) to 78 (flowering) to 60 (final) and *Aphelenchoides spp* from 30 (initial) to 23 (flowering) to 10 (final) and omnivorous (*Dorylaimus spp*) from 81 (initial) to 0 (flowering) to 0 (final) and bacterivorous nematodes from 107 (initial) to 87 (flowering) to 63 (final). In comparison to control in trial one which reduced bacterivores from 200 (initial) to100 (flowering) to 75 (final), predator from 65 (initial) to 6 (flowering) to 4 (final), *Aphelenchus* spp from 280 (initial) to 138 (flowering) to 77 (final), *Aphelechoides* spp from 13 (initial) to 0 (flowering) to 0 (final) and *Dorylaimus* spp from 57 (initial) to 33 (flowering) to 0 (final. The NPK treatment, a chemical fertilizer, pollutes the soil, hence creating an unfavourable environment for FLN. They also do not contribute to microbial activities and organic matter decomposition, hence resulting to a reduced number of free-living nematodes, especially in the final stage. Control treatment means that no amendment was added to the soil, hence, organic matter decomposition was reduced. The soil was also not fertile, hence this contributed to a reduced number of FLN. Biomass in the soil was also reduced and, resulted to no degradation in the soil, hence reducing the number of FLN.

These findings compare to those of Neher (2010), who stated that chemical fertilizers reduced the abundance of free-living nematodes and organic amendments increased bacterivorous. These findings align with those of Ferris *et al*. (2001), who reported that chemical fertilizers reduced nematode diversity by having a negative impact on soil microbial communities. The effect of NPK on bacterivorous was variable and lower compared to FYM. These findings are consistent with those of Qi *et al*. (2023), who reported that nitrogen fertilizer increased the abundance of bacterivore nematodes while phosphorus fertilizer reduced the abundance of bacterivore nematodes. For instance, in trial two at the final stage, NPK had a higher population of bacterivores (104) than the control (10). This shows that when NPK provided essential nutrients for the growth of the plant, it may not have also provided a food source for bacterial nematodes like FYM. These findings are consistent with those of Roul et al. (2017), who reported that NPK fertilizer created unconducive soil conditions, which affected the survival of predator nematodes due to an unstable food web, compared to soil treated with FYM. Natural soil conditions, i.e, plant root interactions and soil biological activity, contributed to the population of free-living nematodes identified in the control treatment.

4.1.2 Plant-parasitic Nematodes Identified in Soil

Table 3 presents the results from trial one and trial two, which determine the effect of different treatments (farmyard manure, Trichoderma harzianum, NPK, and control) on PPNs populations at various growth stages of common beans (initial, flowering, and final). The PPNs identified include Ty*lenchus* spp, *Helicotylenchus* spp, *Meloidogyne* spp, *Trichodorus* spp, *Rotylenchus* spp, *Pratylenchus spp, Hoplolaimus spp,* together with the total nematode count.

Table 3: PPNs identified (100ml of soil) in NPK (23.23.23), FYM, and *Trichoderma harzianum* under Common Beans

Trial	Stage	TRT	*Tylenchus* spp	*Helicotylenchus* spp	Meloidogyne spp	*Trichodorus spp*	*Rotylenchulus* spp	*Pratylenchus* spp	*Hoplolaimus* spp	total
1	Initial	CNT	21	80	0	0	7	20	0	128
		NPK	18	50	0	0	0	65	0	133
		FYM	121	592	0	0	14	200	0	927
		TH	64	276	0	0	100	110	0	550
	Flowering	CNT	30	100	0	0	25	36	0	191
		NPK	24	108	0	0	0	67	0	199
		FYM	42	466	0	0	0	150	0	658
		TH	26	241	0	0	80	80	0	427
	Final	CNT	40	180	42	45	50	100	20	477
		NPK	38	175	6	25	39	85	0	368
		FYM	33	158	0	0	35	70	0	296
		TH	23	137	0	0	7	70	0	237
2	Initial	CNT	40	180	42	45	50	100	20	477
		NPK	38	175	6	25	39	85	0	368
		FYM	33	158	0	0	35	70	0	296
		TH	23	137	0	0	7	70	0	237
	Flowering	CNT	67	197	0	55	51	100	50	520
		NPK	54	205	0	0	91	30	0	380
		FYM	26	68	0	0	0	21	0	115
		TH	0	31	0	7	5	10	0	53
	Final	CNT	85	402	0	130	158	168	125	1068
		NPK	60	300	0	181	95	88	0	724
		FYM	10	30	0	2	1	5	0	48
		TH	0	4	0	0	2	3	0	9

Legend: CNT- control**;** TRT- Treatment; TH.- *Trichoderma harzianum*; FYM- Farmyard manure; Initial- nematodes identified before applying treatments; Flowering- nematodes identified at flowering stage of common beans; Final- nematodes identified after harvesting common beans

Table 4: Effect of NPK, FYM, and *Trichoderma harzianum* on Plant-parasitic Nematodes under Common Beans

TRIAL	STAGE	TREATMENT	PPN IN SOIL
1	Initial	Control	128^{c}
		NPK	133^{c}
		FYM	927^{a}
		TH	550^{b}
	Flowering	Control	191^{c}
		NPK	199^{c}
		FYM	659^{a}
		TH	427^{b}
	Final	Control	477^{a}
		NPK	368^{ab}
		FYM	296^{b}
		TH	237^{b}
2	Initial	Control	477^{a}
		NPK	368^{ab}
		FYM	296^{b}
		TH	237^{b}
	Flowering	Control	520^{a}
		NPK	380^{a}
		FYM	115^{b}
		TH	53^{b}
	Final	Control	1064^{a}
		NPK	727^{b}
		FYM	48^{c}
		TH	9^{c}
		Mean	369.85
		CV (%)	22.15
		LSD(0.05)	182

Legend: CV- Coefficient of Variance; TH- *Trichoderma harzianum*; FYM- Farmyard manure; Initial- nematodes identified before applying treatments; Flowering- nematodes identified at flowering stage of common beans; Final- nematodes identified after harvesting common beans, Means with the same letters within the column are not significantly different at *(P <0.05).*

As shown in Table 4, in trial one, in the initial stage, FYM (927) was significantly different *(p<0.05)* (Appendix 11) from other treatments. *Trichoderma harzianum* (550) was significantly different *(p<0.05)* from control (117) and NPK (133), which were not significantly different. At this stage, treatment had not been applied. At the flowering stage, as common beans continued to grow, counts of PPNs under FYM (659) were significantly different *(p<0.05)* (Appendix 12) from NPK (199), TH (427), and control (191). *Trichoderma harzianum* had fewer PPNs compared to FYM, which showed its ability to suppress PPNs. At the final stage, control (477) was not significantly different from NPK (368), but it showed a significant difference (p <

0.05) (Appendix 13) from TH (237) and FYM (296). In trial two, at the initial stage, a similar trend to that observed in trial one was noted (Appendix 14). At the flowering stage, NPK (380) and control (520) were not significantly different, but they were significantly different *($p<0.05$)* (Appendix 15) from TH (53) and FYM (115). At the final stage, suppressive effects were pronounced. Control (1064) was significantly different ($p<0.05$) (Appendix 16) from NPK (727), TH (9), and FYM (48).

Control increased PPNs because there were no soil amendments added to the soil to manage PPNs. The NPK treatment provided nutrients to common beans, hence promoted root growth and encouraged plenty hosts of PPNs. Chemical fertilizers also provide feeding sites for PPNs. The NPK treatment continued to increase PPNs in the soil by providing a conducive environment for PPNs. Use of NPK resulted in natural suppression of FLN by reducing organic matter decomposition and microbial activity. Chemical fertilizers like NPK also alters the soil conditions like pH, hence favouring PPNs compared to free-living nematodes. Farmyard manure contributed to organic matter decomposition, hence increasing FLN, which suppresses the PPNs. *Trichoderma harzianum* reduced the PPNs by promoting FLN and also acted as a biocontrol agent

As shown in Tables 3 and 4, there were distinct variations in PPNs across three stages in both trials. The highest PPN counts were observed in control and NPK treatments, especially in the final stage, while *Trichoderma harzianum* and FYM treatments significantly reduced PPNs population. Control treatment increased PPNs naturally because there were no amendments added. The NPK treatment encouraged plant growth, especially vigorous root growth, which provided feeding sites for PPNs, which increased the population of PPNs. Farmyard manure reduced plant-parasitic nematodes by encouraging free-living nematodes that suppress PPNs. *Trichoderma harzianum* suppressed PPNs through competition, parasitism, and producing nematicidical metabolites.

In trial two, control treatment showed a progressive increase in PPNs over time from 477 (initial) to 520 (flowering) to 1068 (final), NPK increased from 368 (initial) to 380 (flowering) to 724 (final), while *Trichoderma harzianum* reduced from 237 (initial) to 53 (flowering) to 9 (final). Farmyard manure treatment reduced PPNs from

296 (initial) to 115 (flowering) to 48 (final). Control increased populations of *Pratylenchus spp* from 100 (initial) to 100 (flowering) to 168 (final) and *Helicotylenchus spp* from 180 (initial) to 197 (flowering) to 402 (final), which were the dominant PPNs. Across both trials, in control, *Pratylenchus spp* increased from 20 (initial in trial one) to 168 (final in trial two). *Pratylenchus spp* are also known as root lesion nematodes, and their impact on common beans was root damage, causing lesions as well as reduced root growth. *Pratylenchus spp* reduced nutrient uptake since the roots were damaged. *Meloidogyne spp* was scarce and only found in the control, not at all sampling times, and only once at the final stage (42) in trial one. This is because they mostly live in roots, not soil, where eggs and females are inside the root, and you only catch free J2s, often few or none. Emergence of J2s are linked to temperature.

These findings compare to those of Abd-Elgawad (2020), who reported that soils with no amendment support increased populations of PPNs since there is no competition from nematode antagonists and beneficial microbes. Control had increased populations of *Tylenchus spp* from 40 (initial) to 67 (flowering) to 85 (final), *Meloidogyne spp* from 42 (initial) to 0 (flowering) to 0 (final), *Trichodorus spp* from 45 (initial) to 55 (flowering) to 130 (final), *Rotylenchulus spp* from 50 (initial) to 51 (flowering) to 158 (final), *Hoplolaimus spp* from 20 (initial) to 50 (flowering) to 125 (final) in trial two. In comparison to *Trichoderma harzianum*, which reduced *Tylenchus spp* from 23 (initial) to 0(flowering) to 0(final), *Helicotylenchus spp* from 137 (initial) to 31 (flowering) to 4 (final), *Trichodorus spp* from 0 (initial) to 7 (flowering) to 0 (final), *Rotylenchulus spp* from 7 (initial) to 5 (flowering) to 2 (final), and *Pratylenchus spp* from 70 (initial) to 10 (flowering) to 3 (final).

These findings corroborate with those of Ferris *et al*. (2001), who reported that a decline in organic amendments increases predation and microbial competition. *Hoplolaimus spp* were present in the control but absent in NPK treatments, because they are highly sensitive to chemical inputs and soil disturbances, aligning with findings by Neher *et al*. (2010), which showed that in trial two, *Hoplolaimus spp* populations increased from 20 (initial) to 50 (flowering stage) to 125 (final) in untreated soils. *Rotylenchulus spp* species were more prevalent in control plots, particularly at the final stage, reaching 158 PPNs. The NPK treatment had the second-highest PPN population in both trials, especially at the final stage, where *Helicotylenchus spp* from 175 (initial) to 205 (flowering) to 300 (final), *Pratylenchus spp* from 85 (initial) to 30 (flowering) to 88 (final), and *Trichodoru*s *spp* from 25 (initial) to 0 (flowering) to 181 (final) dominated compared to the control. These findings are consistent with those of Deepali (2023), who reported that synthetic fertilizers cause the PPNs population to increase by enhancing root growth, hence providing additional feeding sites. These findings are consistent with those of Ferris *et al*. (2001), who proposed that chemical fertilizers have a negative impact on nematode diversity by suppressing free-living nematodes like predators and *Dorylaimus spp,* indirectly favouring PPNs.

Farmyard manure substantially decreased PPN populations at all growth stages, leading to significantly lower final counts compared to the control treatment in both trials. For instance, in trial one, there was dominance of *Helicotylenchus spp* in the initial stage (592), which diminished drastically to 158 at the final stage. *Tylenchus spp* from 121(initial) to 42 (flowering) to 33 (final), *Rotylenchulus spp* from 200 (initial) to 150 (flowering) to 70 (final), also reduced drastically. These findings support research by Kimenju *et al*. (2009), which demonstrated that organic amendments like FYM improve soil microbial activity, enhancing antagonistic fungi and bacteria that suppress nematodes. Moreover, among all treatments, *Trichoderma harzianum* exhibited the most significant reduction in PPN populations compared to control treatment in both trials, with species such as *Tylenchus* from 23 (initial) to 0 (flowering) to 0 (final) and *Pratylenchus spp* from 70 (initial) to 10 (flowering) to 3 (final) nearly eliminated by the final stage in trial two. For example, in trial two, the initial *Helicotylenchus spp* population 137 (initial) declined sharply to just 4 (final) at the final sampling. *Trichoderma harzianum* showed a suppressive effect on plant-parasitic nematodes.

These results comply with those of Sharon *et al*. (2011), who highlighted that the biocontrol properties of *Trichoderma harzianum*, attributing its effectiveness to enzyme production that disrupts nematode eggs and juveniles. Furthermore, these findings are in line with those of Neher *et al*. (2010), who emphasized that biocontrol agents contribute to enhanced soil suppressiveness, limiting plant-parasitic nematode proliferation. In contrast to these findings, Lawal & Atungwu (2017) reported that

NPK fertilizer increased plant-parasitic nematodes compared to the control treatment, while organic fertilizer suppressed PPNs.

4.1.3 Effect of NPK (23.23.0), Farmyard manure, and *Trichoderma harzianum* on Shannon Diversity, Simpson's Index of Diversity, and Evenness of Nematodes

Table 5 presents results from two trials determining the effects of different treatments on the diversity and evenness of nematodes at two growth stages: final and initial. The treatments are control, NPK, farmyard manure, and *Trichoderma harzianum*.

Table 5: Effect of NPK (23.23.0), Farmyard manure, and *Trichoderma harzianum* on Shannon Diversity, Simpson's Index of Diversity, and Evenness of Nematodes

Trial	Stage	TRT	Free-living nematodes			Plant-parasitic nematodes		
			Shannon diversity	Simpson's diversity	Evenness	Shannon diversity	Simpson's diversity	Evenness
1	Initial	CNT	1.26	0.67	0.78	1.04	0.56	0.75
		NPK	1.52	0.77	0.94	0.99	0.61	0.90
		FYM	0.96	0.57	0.69	0.95	0.53	0.68
		TH	1.16	0.67	0.84	1.23	0.66	0.89
	Final	CNT	0.79	0.53	0.72	1.71	0.78	0.88
		NPK	0.91	0.57	0.83	1.41	0.70	0.79
		FYM	1.03	0.60	0.74	1.17	0.63	0.85
		TH	1.24	0.67	0.77	1.00	0.25	0.73
2	Initial	CNT	0.79	0.53	0.72	1.71	0.78	0.88
		NPK	0.91	0.57	0.83	1.41	0.70	0.79
		FYM	1.03	0.60	0.74	1.17	0.63	0.85
		TH	1.24	0.67	0.77	1.00	0.25	0.73
	Final	CNT	0.91	0.54	0.82	1.65	0.78	0.92
		NPK	1.44	0.74	0.89	1.44	0.73	0.90
		FYM	0.86	0.47	0.62	1.07	0.56	0.66
		TH	1.46	0.73	0.91	1.06	0.72	0.97

Legend: CNT- control**;** TRT- Treatment; TH- *Trichoderma harzianum*; FYM- Farmyard manure; Initial- before applying treatments and sowing; Final- harvesting common beans

The diversity of FLN and PPNs was calculated using Simpson's and Shannon indices, together with evenness. Ecological indices like Shannon Index, Simpson's index, and Evenness were used to calculate diversity as well as the distribution of PPNs and FLN. Shannon diversity focuses on evenness (how species are equally distributed) and species richness (the total number of species present). Simpson's Index of diversity estimates the likelihood that two randomly chosen individuals from a given sample will be from different species. As presented in Table 5, different treatments had distinct effects on the diversity and evenness of nematodes.

As shown in Table 5, the Shannon diversity index of FLN showed an overall rise, especially *Trichoderma harzianum*, which had the highest increase in both trials. For example, in trial one, Shannon diversity of *Trichoderma harzianum* increased from 1.16 (initial) to 1.24 (final) compared to the control, which reduced from 1.26 (initial) to 0.79 (final). Farmyard manure didn't show a pronounced increase from 0.96 (initial) to 1.03 (final) in diversity because there was dominance of certain nematodes like bacterial feeders, as shown in Table 1. In trial one NPK reduced Shannon diversity of FLN from 1.52 (initial) to 0.92 (final). The NPK treatment created unfavourable conditions for FLN, as well as suppressing FLN. This imbalance reduced evenness, resulting in reduced diversity after application of NPK treatment. Simpson's index of diversity of FLN had a comparable trend. *Trichoderma harzianum* increased Simpson's index of diversity in trial two from 0.67 (initial) to 0.73 (final) compared to the control, which did not show a significant increase from 0.53 (initial) to 0.54 (final). These results show that there was a reduction in species dominance, resulting in a balanced nematode community because the control treatment did not increase the number of FLN, while *Trichoderma harzianum* increased. *Trichoderma harzianum* reduced dominant PPNs and suppressed them, resulting in higher evenness and a balanced community.

Evenness values of FLN remained relatively consistent across the different treatments, suggesting that species distribution did not change significantly despite increases in overall diversity. The *Trichoderma harzianum* treatment recorded the highest final evenness value (0.91) in trial two, reflecting a well-balanced distribution within the nematode community. In comparison, the control treatment had a final value of Evenness of 0.82. These results compare to those of Rigobelo *et al*. (2024), who studied the effects of *T. harzianum* on the diversity of root and soil microbiomes in soybean plants and found that soil samples treated with *T. harzianum* exhibited increased richness and diversity, as measured by both Shannon and Gini-Simpson indices, suggesting a positive impact on soil microbial diversity.

Shannon diversity index for plant-parasitic nematodes showed mixed responses across treatments. Control treatment showed the highest increase in the Shannon diversity index. For instance, in trial one, diversity increased from 1.04 (initial) to 1.71 (final). NPK showed a slight increase from 0.99 (initial) to 1.41 (final) while *Trichoderma harzianum* reduced from 1.23 (initial) to 1.00 (final). Control increased the diversity because no soil amendment was added, and no soil disturbance occurred. This made more PPNs coexist and survive without competition or suppression, resulting in high evenness. However, the *Trichoderma harzianum* from 1.23 (initial) to 1.00 (final) and FYM from 0.95 (initial) to 1.17 (final) treatments exhibited relatively stable values, suggesting that these treatments may not significantly impact plant-parasitic nematode diversity. Farmyard manure and *Trichoderma harzianum* reduced Shannon diversity of PPNs because they created conditions unfavourable for plant-parasitic nematodes. *Trichoderma harzianum* is a biocontrol, hence it suppressed the plant-parasitic nematodes while FYM promoted the FLN. This selection pressure resulted in reduced dominant species, hence a drop in diversity. The NPK treatment increased Shannon diversity from 0.99 (initial) to 1.41 (final) because it enhanced the growth of common beans, providing more nutrients and roots, which supported plant-parasitic nematodes. This also increased evenness, resulting in a high Shannon diversity.

In trial one, Simpson's Index of Diversity for plant-parasitic nematodes increased in the control from 0.56 (initial) to 0.78 (final) and NPK from 0.61 (initial) to 0.70 (final), implying reduced dominance by a few species. However, *Trichoderma harzianum* showed a decline in Simpson's index from 0.66 (initial) to 0.25 (final), suggesting that a few plant-parasitic nematode species may have become dominant under this treatment. Evenness values fluctuated across treatments, with *Trichoderma harzianum* showing a final increase from 0.73 (initial) to 0.96 (final) in trial two, suggesting a more uniform distribution of plant-parasitic nematodes. These findings are consistent with those of Dash *et al*. (2018), who reported that the use of NPK increased the nematode diversity and populations of PPNs. These findings are contrary to those of Qi *et al*. (2023), who reported that nitrogen and phosphorus fertilizers affected the diversity of soil nematode communities.

4.2 Effect of NPK (23.23.0), *Trichoderma Harzianum*, and Farmyard Manure on Common Beans' Growth and Yield Components.

4.2.1 Effect of NPK (23.23.0), *Trichoderma harzianum*, and Farmyard Manure on Common Beans' Seed Emergency

Seed emergence is a critical early stage of seed vigour and subsequent crop establishment in legumes, including common beans (*Phaseolus vulgaris*). Table 6 presents the percentage of seed emergence under four different treatments: NPK (23.23.0), farmyard manure, *Trichoderma harizianum,* and control**,** across two trials. In trial 1, *Trichoderma harzianum* had the highest emergence (92.5%), while in Trial 2, FYM led with 93.33%. Notably, all treatments were not significantly different (p>0.05) (Appendix 20 and 21) since they shared grouping letter "a" and the Least Significant Difference (LSD $(_{0.05})$ value of 17.20, which exceeds the observed differences among treatments.

Table 6: Effect of NPK (23.23.0), Farmyard Manure, and *Trichoderma harizianum* on Seed Emergence of Common Beans.

TRIAL	TREATMENT	Seed Emergence (%)
1	Control	83.33[a]
	NPK	79.17[a]
	Farmyard manure	86.67[a]
	Trichoderma harzianum	92.50[a]
2	Control	84.17[a]
	NPK	84.17[a]
	Farmyard manure	93.33[a]
	Trichoderma harzianum	77.50[a]
	Mean	85.10
	CV (%)	16.59
	$LSD_{(0.05)}$	17.20

Legend: CV- Coefficient of variation, Means with the same letters within the column are not significantly different at (P <0.05).

As presented in Table 6, in trial one, *Trichoderma harzianum* had the highest seed emergence of 92.50% compared to the control, which had 83.33%. In trial two, farmyard manure had the highest seed emergence of 93.33% compared to the control, which had 84.17%. Inconsistent seed emergence of *Trichoderma harzianum* in both trials, 92.50% in trial one and 77.50% in trial two, compared to the control, which had 83.33% in trial one and 84.17% in trial two, could have been caused by factors like different environmental conditions (moisture content and soil temperature) between trials, which influence the efficacy of microbial inoculants. FYM had relatively good seed emergence in both trials, 86.67% in trial one and 93.33% in trial two, compared to the control, which had 83.33% in trial one and 84.17% in trial two. This indicates that germination was primarily determined by seed vigour and uniform germination conditions rather than treatment effects. Emergence was dependent on existing environmental and soil conditions, which were adequate for initial germination.

Despite lack of significant differences, these findings are contrary to those of Harman *et al*. (2004), who reported that *Trichoderma harzianum* has been shown to enhance seed emergence through mechanisms like improved nutrient availability, phytohormone production, and biocontrol of pathogens. The findings are contrary to those of Singh *et al*. (2024), who reported that organic amendments enhance soil structure and microbial activity, creating favourable conditions for plant development beyond germination. These findings are contrary to those of Yang (2017), who reported that the application of balanced NPK fertilizer increased the percentage and germination ability of seeds.

4.2.2 Effect of NPK (23.23.0), *Trichoderma harzianum,* and Farmyard Manure on Common Beans' Height

Table 7 presents the results on the height (in cm) of common bean crops recorded at 14, 28, 42, and 56 days after sowing (DAS) under different treatments across the two trials. The treatments included NPK fertilizer, control, *Trichoderma harzianum,* and farmyard manure. Each treatment showed a significant difference ($p<0.05$) (Appendix 23 to 30) in height of common beans over time, where NPK had the tallest plants in both trials, followed by farmyard manure, *Trichoderma harzianum,* and control. CV and LSD ($\alpha=0.05$) were used to show the significance and reliability of observed differences.

As shown in Table 7, there were significant differences *($P<0.05$)* (Appendix 23 to 30) among all treatments. Trial two had higher growth responses compared to trial one, but similar trends were observed in trial two. This showed that there was residual fertility, and soil conditions improved. Looking at the trends in both trials on the increase of plant height from 14 to 28 to 42 to 56 DAS, NPK had the highest increase, followed by FYM, then *Trichoderma harzianum,* and Control was the last. The NPK treatment had the tallest plants in both trials compared to the control treatment and the other treatments. The NPK treatment supplied readily available nutrients, which accelerated growth, hence increased the height of common beans, while FYM slowly released nutrients for common bean uptake, improved water retention, soil structure, and microbial activity for plant growth. *Trichoderma harzianum* enhanced nutrient uptake but to a lesser extend compared to NPK and FYM, root health indirectly supporting common bean growth. In comparison to control, which depended solely on existing soil fertility, which limited common bean development and reduced overall growth performance.

Table 7: Effects of NPK (23.23.0), Farmyard manure, and *Trichoderma harzianum* on the Height of Common Beans.

TRIAL	TREATMENT	HEIGHT (in cm)			
		14 DAS	28 DAS	42 DAS	56 DAS
1	Control	8.25^{d}	14.58^{d}	18.92^{d}	26.17^{d}
	NPK	19.75^{a}	35.17^{a}	50.42^{a}	66.67^{a}
	Farmyard manure	15.75^{b}	29.83^{b}	39.17^{b}	55.33^{b}
	Trichoderma harzianum	12.75^{c}	21.58^{c}	29.83^{c}	40.42^{c}
II	Control	8.08^{d}	10.58^{d}	35.25^{d}	52.00^{d}
	NPK	16.25^{a}	59.50^{a}	96.67^{a}	104.92^{a}
	Farmyard manure	13.25^{b}	30.25^{b}	77.00^{b}	85.67^{b}
	Trichoderma harzianum	10.58^{c}	19.58^{c}	58.58^{c}	67.42^{c}
	Mean	13.07	27.64	50.72	62.32
	CV (%)	14.96	33.19	27.17	20.40
	$LSD_{(0.05)}$	1.123	5.263	7.908	7.296

Legend: CV- Coefficient of variation; DAS- Days after sowing. Means with the same letters within the column are not significantly different at ($P < 0.05$).

As shown in Table 7, for instance, in trial two, NPK treatment increased height from 16.25 at 14 DAS to 59.50 at 28 DAS to 96.67 at 42 DAS to 104.92 at 56 DAS compared to control, which increased from 8.08 at 14 DAS to 10.58 at 28 DAS to 35.25 at 42 DAS to 52.00 at 56 DAS. The NPK treatment provided readily available macro-nutrients, that is, nitrogen and phosphorus, which are essential for the growth of common beans. Nitrogen is one of the key elements in shoot and leaf development. Phosphorus plays vital roles like helping in cell division, energy transfer, and root development. Farmyard manure was ranked second in both trials. For instance, in trial one, FYM increased plant height from 15.75 at 14 DAS to 29.83 at 28 DAS to 39.17 at 42 DAS to 55.33 at 56 DAS compared to the control, which increased from 8.25 at 14 DAS to 14.58 at 28 DAS to 18.92 at 42 DAS to 26.17 at 56 DAS. Plants in plots treated with FYM were taller compared to those with no treatment and *Trichoderma harzianum*. Farmyard manure led to an increase in plant height because of the presence of organic matter, which improved soil fertility and provided essential nutrients gradually.

Trichoderma harzianum showed less pronounced results on plant height compared to NPK and FYM. For instance, in trial two, *Trichoderma harzianum* increased plant height from 10.58 at 14 DAS to 19.58 at 28 DAS to 58.58 at 42 DAS to 67.42 at 56 DAS compared to the control, which increased from 8.08 at 14 DAS to 10.58 at 28 DAS to 35.25 at 42 DAS to 52.00 at 56 DAS. However, *Trichoderma harzianum* encouraged growth compared to control treatment. *Trichoderma harzianum* increased the growth of common beans by producing growth regulators. Control increased plant height from 8.25 at 14 DAS to 14.58 at 28 DAS to 18.92 at 42 DAS to 26.17 at 56 DAS in trial one and increased from 8.08 at 14 DAS to 10.58 at 28 DAS to 35.25 at 42 DAS to 52.00 at 56 DAS in trial two. Control treatment had the shortest plants compared to all other treatments, this is because there were no amendments added to the soil.

These findings compare to those of Halifu *et al*. (2019), who showed that when *Trichoderma spp*. is applied in the plant's rhizosphere, it promotes morphological traits like height, number of branches, leaves, biomass, and shoot-root length. These findings corroborate with those of Uddin *et al*. (2023), who reported that NPK fertilizer increased the plant height compared to farmyard manure of garden pea. These findings are in line with those of Khan *et al*. (2021), who suggested that organic manures not only increased growth but also nutrient uptake compared to the control treatment in chickpea. These findings are consistent with Ali *et al*. (2023), who reported that organic fertilizers applied at the rate of 600 $kgha^{-1}$ increased the plant height compared to the control in common beans. These results are inconsistent with those of El-Yazal (2020), who reported that FYM increased plant height compared to NPK and control treatment in broad beans. These findings contrast those of Hossain & Akter (2020), who reported that *Trichoderma spp* increased growth compared to farmyard manure and control treatment, which had a lower growth rate of brinjal.

4.2.3 Effects of NPK (23.23.0), Farmyard manure, and *Trichoderma harzianum* on the Number of Leaves and Branches of Common Beans

Tables 8 and 9 present the results of the number of branches and leaves of common beans, respectively. There was a significant difference ($p<0.05$) in the number of branches across all treatments in both trials. There was no significant difference ($p>0.05$) in trial one between FYM and *Trichoderma harzianum* on 56 DAS, but there was a significant difference ($p<0.05$) (Appendix 35 to 42) in trial two across all treatments in the number of leaves.

Table 8: Effects of NPK (23.23.0), Farmyard manure, and *Trichoderma harzianum* on Number of Branches of Common Beans.

TRIAL	TREATMENT	NUMBER OF BRANCHES			
		14 DAS	28 DAS	42 DAS	56 DAS
I	Control	1.58^{c}	2.67^{d}	3.92^{c}	4.50^{d}
	NPK	2.50^{a}	8.58^{a}	13.08^{a}	15.00^{a}
	Farmyard manure	2.08^{b}	5.91^{b}	8.58^{b}	9.83^{b}
	Trichoderma harzianum	2.00^{b}	4.25^{c}	6.58^{c}	7.92^{c}
II	Control	0.50^{c}	2.25^{d}	5.42^{d}	7.00^{d}
	NPK	1.42^{a}	8.42^{a}	28.08^{a}	32.08^{a}
	Farmyard manure	1.00^{b}	5.58^{b}	15.67^{b}	20.75^{b}
	Trichoderma harzianum	0.92^{b}	3.42^{c}	9.33^{c}	12.41^{c}
	Mean	1.5	5.14	11.33	13.69
	CV (%)	25.56	20.45	34.19	33.46
	$LSD_{(0.05)}$	0.22	0.60	2.22	2.63

Legend: CV- Coefficient of variation; DAS- Days after sowing, Means with the same letters within the column are not significantly different at ($P <0.05$).

Table 9: Effects of NPK (23.23.0), Farmyard manure, and *Trichoderma harzianum* on the Number of Leaves of Common Beans.

TRIAL	TREATMENT	NUMBER OF LEAVES			
		14 DAS	28 DAS	42 DAS	56 DAS
I	Control	6.75[c]	10.00[d]	13.75[d]	15.50[c]
	NPK	9.50[a]	27.75[a]	41.25[a]	47.00[a]
	Farmyard manure	8.25[b]	19.75[b]	27.75[b]	31.00[b]
	Trichoderma harzianum	8.00[b]	14.75[c]	21.75[c]	25.75[b]
II	Control	3.50[c]	8.75d	18.25[d]	23.00[d]
	NPK	6.25[a]	27.25[a]	86.25[a]	98.25[a]
	Farmyard manure	5.00[b]	18.75[b]	49.00[b]	64.25[b]
	Trichoderma harzianum	4.75[b]	12.25[c]	30.00[c]	39.25[c]
	Mean	6.5	17.41	36	43
	CV (%)	17.70	18.10	32.29	32.08
	$LSD_{(0.05)}$	0.66	1.81	6.67	7.92

Legend: CV- Coefficient of variation; DAS- Days after sowing, Means with the same letters within the column are not significantly different at (P <0.05).

The number of leaves and branches is a generally critical vegetative characteristic that contributes to the architecture, reproductive potential, and biomass production. The NPK treatment showed the highest number of leaves and branches in both trials, followed by farmyard manure, *Trichoderma harzianum*, and control. The trends observed in both trials were similar for the number of leaves and branches. Trial two had a higher number of leaves and branches compared to trial one this is because there was residual fertility, and soil conditions improved.

As shown in Tables 8 and 9, looking at the trends in both trials on the increase of the number of branches and leaves from 14 to 28 to 42 to 56 DAS, NPK had the highest increase, followed by FYM, then *Trichoderma harzianum*, and Control had the least. The NPK treatment supplied readily available nutrients, which accelerated growth, hence the highest number of leaves and branches, while FYM slowly released nutrients for common bean uptake, improved water retention, soil structure, and microbial activity for plant growth. *Trichoderma harzianum* enhanced nutrient uptake but to a lesser extend compared to NPK and FYM, root health indirectly supporting moderate growth. In comparison to the control, which depended solely on existing soil fertility, which limited common bean development and reduced overall growth performance.

For instance, in trial one, NPK fertilizer increased the number of branches of common beans from 2.50 at 14 DAS to 8.58 at 28 DAS to 13.08 at 42 DAS to 15.00 at 56

DAS, while control increased from 1.58 at 14 DAS to 2.67 at 28 DAS to 3.92 at 42 DAS to 4.50 at 56 DAS. Table 9 shows that NPK, for instance, in trial one, increased the number of leaves from 9.50 at 14 DAS to 27.75 at 28 DAS to 41.25 at 42 DAS to 47.00 at 56 DAS, while control increased from 6.75 at 14 DAS to 10.00 at 28 DAS to 13.75 at 42 DAS to 15.50 at 56 DAS. The NPK treatment provided essential macronutrients, that is, nitrogen and phosphorus, which play key roles in processes of vegetative growth like cell differentiation, elongation, and cell division. Nitrogen played a key role in shoot growth as well as new branches. Nitrogen made leaves greener because of increased chlorophyll that was produced. Phosphorus aids in root development and energy transfer, which promotes shoot proliferation. Phosphorus also improves the strength of branches and stems and overall health.

Farmyard manure also influenced the number of leaves and branches compared to *Trichoderma harzianum* and the control in both trials. For example, in trial two, FYM increased the number of branches (as shown in Table 6) from 1.00 at 14 DAS to 5.58 at 28 DAS to 15.67 at 42 DAS to 20.75 at 56 DAS, while the control increased from 0.50 at 14 DAS to 2.25 at 28 DAS to 5.42 at 42 DAS to 7.00 at 56 DAS. As presented in Table 7 in trial two, FYM increased the number of leaves from 5.00 at 14 DAS to 18.75 at 28 DAS to 49.00 at 42 DAS to 64.25 at 56 DAS compared to control 3.50 at 14 DAS to 8.75 at 28 DAS to 18.25 at 42 DAS to 23.00 at 56 DAS. Farmyard manure was less effective compared to NPK. These findings concur with earlier findings, which state that organic amendments like farmyard manure release nutrients gradually and are influenced by microbial mineralization for nutrients to be available for the plant. The increase in the number of leaves and branches over time showed that there was a gradual release of nutrients that sustained vegetative growth. This was evident on the last day of data collection (56 DAS).

Trichoderma harzianum had a higher effectiveness compared to the control treatment on the number of branches and leaves. Table 8 shows *Trichoderma harzianum,* for instance, in trial one increased the number of branches from 2.00 at 14 DAS to 4.25 at 28 DAS to 6.58 at 42 DAS to 7.92 at 56 DAS, compared to the control, which increased from 1.58 at 14 DAS to 2.67 at 28 DAS to 3.92 at 42 DAS to 4.50 at 56 DAS. In trial two, Table 9 shows *Trichoderma harzianum* increased the number of leaves from 4.75 at 14 DAS to 12.25 at 28 DAS to 30.00 at 42 DAS to 39.25 at 56

DAS compared to the control, which increased from 3.50 at 14 DAS to 8.75 at 28 DAS to 18.25 at 42 DAS to 23.00^{d} at 56 DAS. *Trichoderma harzianum* had a lower effect on shoot development compared to the direct application of nutrient amendments like NPK. Control treatment was the last in terms of the number of branches and leaves compared to all other treatments. This is because there were no essential nutrients added to the soil to promote plant growth.

These findings are in line with those of Raksun *et al.* (2022), who reported that NPK fertilizer increased the number of leaves, leaf width, stem length, and leaf length of long beans. These findings are consistent with those of Ali *et al.* (2023), who reported that organic fertilizers applied at the rate of 600 $kgha^{-1}$ increased the number of branches compared to the control in common beans. These findings corroborate with those of Sofo *et al.* (2010), who reported that there was increased root growth and reduced shoot growth in prunus rootstock. These results are inconsistent with those of El-Yazal (2020), who reported that FYM increased the number of branches compared to NPK and control treatment in broad beans. These findings are contrary to those of Naluzze (2022), who reported that there was no significant difference ($P>0.05$) in the number of leaves when NPK and cattle manure were applied compared to the control in common beans.

4.2.4 Effect of NPK (23.23.0), Farmyard manure, and *Trichoderma harizianum* on the Number of Pods and Seeds of Common Beans

Table 10 represents the number of common bean pods and seeds produced, respectively. There was a significant difference ($p<0.05$) (Appendix 59 to 63) in all the treatments in both trials in terms of the number of pods and seeds. The NPK treatment was the most effective treatment with the highest number of pods and seeds in both trials compared to the control treatment. There were similar trends observed in both trials. As presented in Table 10, looking at the trends in both trials on the number of pods and seeds, NPK had the highest, followed by FYM, then *Trichoderma harzianum,* and Control was the last. The NPK treatment supplied readily available nutrients, which accelerated growth, hence the highest number of pods and leaves, while FYM slowly released nutrients for common bean uptake, improved water retention, soil structure, and microbial activity for plant growth. *Trichoderma harzianum* enhanced nutrient uptake but at a lesser extend compared to NPK and

FYM, root health indirectly supporting moderate growth. In comparison to the control, which depended solely on existing soil fertility, which limited common bean development and reduced overall growth performance.

Table 10: Effect of NPK (23.23.0), Farmyard manure, and *Trichoderma harizianum* on the Number of Pods and Seeds of Common Beans.

TRIAL	TREATMENT	NUMBER OF PODS	NUMBER OF SEEDS
1	Control	6.00[d]	33.70[d]
	NPK	25.10[a]	176.77[a]
	Farmyard manure	17.37[b]	121.63[b]
	TH	11.33[c]	64.90[c]
2	Control	5.73[d]	31.63[d]
	NPK	25.57[a]	162.00[a]
	Farmyard manure	18.03[b]	112.13[b]
	TH	11.37[c]	69.77[c]
	Mean	15.06	96.57
	CV (%)	20.01	26.51
	$LSD_{(0.05)}$	1.085	9.21

Legend: TH- *Trichoderma harzianum*, CV- Coefficient of variation, Means with the same letters within the column are not significantly different at ($P < 0.05$).

As shown in Table 10 NPK treatment had the highest number of pods 25.10 (trial one) and 25.57 (trial two) and seeds 176.77 (trial one) and 162.00 (trial two) compared to control which had the least number of pods 6.00 (trial one) and 5.73 (trial two) and seeds 33.70 (trial one) and 31.63 (trial two). The NPK treatment emerged as the best because of the supply of essential macronutrients, which played vital roles in flowering, pod development, seed formation, and filling. Farmyard manure had the second highest treatment number of pods of 17.37 (trial one) and 18.03 (trial two) and number of seeds were 121.63 (trial one) and 112.13 (trial two) compared to control which had the least number of pods 6.00 (trial one) and 5.73 (trial two) and seeds 33.70 (trial one) and 31.63 (trial two) in both trials. Farmyard manure improves the soil's physical properties and aeration, and enhances water retention and infiltration. It aids in the slow release of micro and macro nutrients, which become available to the common bean plant. Moreover, it enriches microbial populations in soil, leading to a healthy rhizosphere that can help in nutrient uptake and nutrient cycling. Farmyard manure has long-term benefits like sustained fertility and enhanced soil structure, which indirectly contribute to an increased number of pods and seeds.

Trichoderma harzianum had 11.33 (trial one) with and 11.37 (trial two) number of pods and seeds with 64.90 (trial one) and 69.77 (trial two) compared to control treatment which had the lowest number of pods 6.00 (trial one) and 5.73 (trial two) and seeds 33.70 (trial one) and 31.63 (trial two) in both trials. *Trichoderma harzianum* is known to promote growth through root development, disease suppression, and nutrient solubilisation, but to a lesser extend compared to NPK and FYM. Control treatment had the lowest number of pods of 6.00 (trial one) and 5.73 (trial two), and seeds 33.70 (trial one) and 31.63 (trial two) in both trials. This shows that there is a need for intervention in order to increase the production of seeds and pods. These findings corroborate with those of Wijanarko *et al*. (2016), who reported that the application of NPK fertilizer increased the number of pods compared to the control in soybean.

Similar findings were reported by Zamukulu *et al*. (2023), who found that NPK fertilizer increased the number of seeds per plant compared to the control. These findings aligned with those of Tadesse & Abera (2023), who reported that application of farmyard manure increased the number of pods and seeds per plant in haricot bean. These findings align with those of Ali *et al*. (2023), who reported that organic fertilizers applied at the rate of 600 $kgha^{-1}$ increased the number of seeds and number of pods compared to the control in common beans. These findings corroborate with those of Mahmoodian *et al*. (2022), who reported that *Trichoderma harzianum* increased the number of pods and seeds compared to the control. These results are inconsistent with those of El-Yazal (2020), who reported that FYM increased the number of seeds and branches compared to NPK and control treatment in broad beans. These findings are contrary to those of Naluzze (2022), who reported that there was no significant difference (P>0.05) in the number of pods and seeds when NPK and cattle manure were applied compared to the control in common beans.

4.2.5 Effect of NPK (23.23.0), Farmyard Manure, and *Trichoderma harizianum* on Grain and Biomass Yields of Common Beans

Biomass produced is an essential indicator of plant vigour and the ability to capture as well as convert sunlight energy to usable energy by the process of photosynthesis, which is linked to water-use-efficiency and nutrient uptake. As presented in Table 11, there were significant differences (p<0.05) (Appendix 65 to 69) in grain and biomass yields of common beans among NPK, FYM, and *Trichoderma harzianum* treatments. Still, *Trichoderma harzianum* and control did not show a significant difference ($p>0.05$) in yields (trials 1 and 2) and biomass (trial 1). In trial two, there were significant differences ($p<0.05$) among all treatments in biomass.

Table 11: Effect of NPK (23.23.0), Farmyard manure, and *Trichoderma harizianum* on Grain and Biomass Yields of Common Beans.

TRIAL	TREATMENT	GRAIN YIELDS (kg/ha)	BIOMASS (kg/ha)
1	Control	385.19[c]	196.88[c]
	NPK	3950.62[a]	1269.25[a]
	Farmyard manure	2437.67[b]	656.53[b]
	Trichoderma harzianum	923.33 [c]	372.27[c]
2	Control	787.65[c]	189.59[d]
	NPK	5234.57[a]	1154.18[a]
	Farmyard manure	3061.73[b]	714.67[b]
	Trichoderma harzianum	1354.32[c]	361.01[c]
	Mean	2192.81	614.30
	CV (%)	31.85	13.25
	$LSD_{(0.05)}$	850.76	99.12

Legend: CV- Coefficient of variation; Means with the same letters within the column are not significantly different at ($P <0.05$)

As shown in Table 11, looking at the trends in both trials on the increase of grain yield and biomass, NPK had the highest, followed by FYM, then *Trichoderma harzianum,* and Control had the least. The NPK treatment supplied readily available nutrients, which accelerated growth, hence the highest grain yield and biomass, while FYM slowly released nutrients for common bean uptake, improved water retention, soil structure, and microbial activity for plant growth. *Trichoderma harzianum* enhanced nutrient uptake but at a lesser extend compared to NPK and FYM, root health indirectly supporting moderate growth. In comparison to the control, which depended solely on existing soil fertility, which limited common bean development and reduced overall growth performance. The NPK treatment had the highest grain yields of 3950.62 (trial 1) and 5234.57 (trial 2), and biomass of 1269.25 (trial 1) and 1154.18 (trial 2), while control had the lowest yield of 385.19 (trial1) and 787.65 (trial 2) and biomass of 196.88 (trial1) and 189.59 (trial two) in both trials.

The NPK treatment provided readily available nutrients for physiological processes. The performance was contributed by readily available nutrients, i.e., nitrogen and phosphorus, which are essential for leaf development, cell division, energy transfer, and root expansion within common beans. The results showed the effectiveness of NPK fertilizer in maximising common bean growth and biomass, which also contributed to increased yield. Farmyard manure was the second among other treatments with yield of 2437.67 (trial 1) and 3061.73 (trial 2) and biomass of 656.53 (trial 1) and 714.67 (trial 2) compared to control which had the lowest yield of 385.19 (trial1) and 787.65 (trial 2) and biomass of 196.88 (trial1) and 189.59 (trial two) in both trials. Farmyard manure showed the value of organic inputs in improving crop productivity and soil fertility, because of enhanced water retention and soil structure. Though it was less effective compared to NPK, farmyard manure offers agronomic and environmental advantages. The increase in the amount of biomass under farmyard manure application shows its ability to become an organic alternative to synthetic fertilizers.

Trichoderma harzianum as a bio-fertilizer illustrated a grain yield of 923.33 (trial 1) and 1354.32 (trial 2) and biomass of 372.27 (trial 1) and 361.01 (trial 2) in comparison to control, which had the lowest grain yield of 385.19 (trial 1) and 787.65 (trial 2) and biomass of 196.88 (trial 1) and 189.59 (trial two) in both trials. However, the grain yield of *Trichoderma harzianum* was lower compared to FYM and NPK. It showed its potential in increasing vegetative growth by nutrient mobilisation and enhanced root health. Control treatment had the lowest grain yield of 385.19 (trial 1) and 787.65 (trial 2), and biomass of 196.88 (trial 1) and 189.59 (trial 2) produced in both trials, but there was no statistically significant difference ($p>0.05$) with *Trichoderma harzianum* except on biomass (trial 2). This reflected that there was a nutrient deficiency in the soil, and this suggests external inputs should be added to the soil in order to support vegetative growth.

These findings, which corroborate with those of Mndzebele *et al*. (2023), showed that application of NPK fertilizer increased biomass accumulation in cowpea-amaranth intercrop. These findings align with those of Zamukulu *et al*. (2023), who observed that application of 150 kg per ha of NPK fertilizer led to increased yield of common bean from 1.1 to 1.5 tons per ha. These results are consistent with those of Rurangwa *et al*. (2018), who demonstrated that manure significantly increased grain yield and biomass of soybean and common bean in comparison to untreated soils. These results corroborate with those of Upenji (2020), who showed that manure improved the yield of common bean compared to the control.

These findings corroborate with those of Ali *et al*. (2023), who reported that organic fertilizers applied at the rate of 600 $kgha^{-1}$ increased the grain yield and dry matter compared to the control in common beans. These findings are in line with those of Pereira *et al*. (2014), who reported that *Trichoderma harzianum* improved the growth of common bean; hence, there is a potential increase in yield. These results comply with those of Mahmoodian *et al*. (2022), who reported that inoculation of *Trichoderma harzianum* led to increased total biomass compared to the control. These results are inconsistent with those of El-Yazal (2020), who reported that FYM increased yields compared to NPK and control treatment in broad beans. These findings are contrary to those of Alhrout *et al*. (2018), who reported that FYM showed increased yield compared to NPK and control in tomato.

4.3 Effect of NPK (23.23.0), *Trichoderma Harzianum,* and Farmyard Manure on Plant-parasitic Nematodes in the Roots of Common Beans.

4.3.1 Effect of NPK (23.23.0), *Trichoderma harzianum,* and Farmyard Manure on the Number of Common Beans Root Nodules

Table 12 presents the number of nodules from two trials determining the effect of different treatments on the number of nodules of common beans. The treatments were; *Trichoderma harzianum*, NPK, control, and farmyard manure. In every trial, the average number of nodules was reported for each treatment, together with a statistical comparison indicated by the letters a, b, c, and d. The table also provides an overall "Mean" number of nodules across all treatments and trials, a "CV (%)" (Coefficient of Variation) indicating the variability of the data, and "LSD" (Least Significant Difference at the 0.05 level), which was used to determine statistically significant differences among treatment means.

Table 12: Effect of NPK (23.23.0), Farmyard manure, and *Trichoderma harizianum* on the Number of Root nodules of Common Beans.

TRIAL	TREATMENT	NUMBER OF NODULES
1	Control	5.56^{c}
	NPK	2.44^{c}
	Farmyard manure	14.11^{b}
	Trichoderma harzianum	41.00^{a}
2	Control	17.67^{c}
	NPK	3.44^{d}
	Farmyard manure	32.89^{b}
	Trichoderma harzianum	60.00^{a}
	Mean	22.14
	CV (%)	34.61
	$LSD_{(0.05)}$	5.102

Legend: CV- Coefficient of variation, Means with the same letters within the column are not significantly different at ($P < 0.05$)

Nodulation in common beans is an essential parameter that shows the symbiotic interaction between nitrogen-fixing bacteria and the plant. Soil amendments like organic inputs, bioinoculants, and inorganic fertilizers influence these symbiosis interactions. Table 12 shows that there were significant differences ($p<0.05$) (Appendix 71 and 72) among the treatments in terms of their effect on the nodulation of common beans. Looking at the trends in both trials on the number of nodules, *Trichoderma harzianum* had the highest, as shown in Figure 5, followed by FYM, as shown in Figure 2, then Control, as shown in Figure 3, and NPK, as shown in Figure 4, had the least. *Trichoderma harzianum* increased nodules by encouraging symbiosis with rhizobia and root health, resulting in more nodules. Farmyard manure improved microbial activity and soil fertility, hence boosting nodulation. The NPK treatment input reduced rhizobial infection, leading to least nodules, while the control had no amendment added.

Trichoderma harzianum had the highest number of nodules in both trials, with 41.00 in trial one and 60.00 in trial two, and NPK had the lowest number, 2.44 in trial one and 3.44 in trial 2, in comparison to the control, which had the fewest nodules, 5.56 in trial one and 17.67 in trial 2. *Trichoderma harzianum* promoted nodulation in common beans by enhancing root growth and microbial activity, hence improved rhizobial colonisation. *Trichoderma* secretes metabolites like indole-3-acetic acid, which promote rhizobia interaction. Farmyard manure was the second in the number of nodules in both trials, with 14.11 in trial 1 and 32.89 in trial two, compared to the control, which had 5.56 in trial one and 17.67 in trial 2, and its effects were less compared to *Trichoderma harzianum,* since it does not have directly bioactive compounds which stimulate nodulation. Farmyard manure can enhance soil structure and improve microbial biomass, and nutrients are released slowly, which favours the common bean plant and rhizobia.

As shown in Figure 4, NPK had the lowest number of nodules. The NPK treatment had the lowest number of nodules of 2.44 in trial one and 3.44 in trial 2, compared to the control, which had 5.56 in trial one and 17.67 in trial 2. The NPK treatment did not support the growth of root nodules since it presented a suppressive effect in terms of nodulation. The control treatment had a higher number of nodules compared to NPK, showing that nodulation occurred naturally in the soil but at a slower rate than in FYM and *Trichoderma harzianum* treatments. These findings corroborate with those of Mweetwa *et al*. (2016), who reported that inoculation of *Trichoderma* led to an increased number of nodules.

These findings are consistent with those of Otieno *et al*. (2009), who carried out a study involving legumes like lablab, lima bean, green gram, and common bean, and found that application of farmyard manure increased the number of root nodules compared to the control treatment. This outcome was contributed to by slow mineralisation, resulting in the gradual release of nitrogen as well as phosphorus in the farmyard manure. These findings are in line with those of Dos *et al*. (2022), who reported that application of nitrogen fertilizer reduced the reliance of the plant on biological nitrogen fixation. When mineral nitrogen is available, legumes do not concentrate on nodules formation since they can get the nitrogen required by the crop without involving symbiosis. These findings are contrary to those of Sulieman & Hago (2009), who reported that farmyard manure did not have a significant effect on nodulation compared to control in common beans.


Figure 2: Common bean root from Farmyard manure treatment

Figure 3: Common bean root from control treatment

Figure 4: Common bean root from NPK (23.23.0) treatment

Figure 5: Common bean root from *Trichoderma harzianum* treatment

4.3.2 Effect of NPK (23.23.0), *Trichoderma harzianum,* and Farmyard Manure on Plant-parasitic Nematodes in Roots of Common Bean

Table 13 shows results from trial one and trial two, determining the effect of different treatments (farmyard manure, *Trichoderma harzianum,* NPK, and control) on PPNs populations in the roots of common beans. The PPNs identified were: Ty*lenchus spp*, *Helicotylenchus spp*, *Rotylenchus spp*, and *Pratylenchus spp.*

Table 13: The Number of Plant-parasitic Nematodes Identified in Roots (5g) of Common Beans under NPK, *Trichoderma harzianum,* and Farmyard Manure

Trial	TRT	*Tylenchus spp*	*Helicotylenchus spp*	*Rotylenchulus spp*	*Pratylenchus spp*	total
1	Control	0	18	0	0	18
	NPK	4	19	10	10	43
	FYM	0	0	0	0	0
	TH	0	0	0	0	0
2	Control	16	5	12	30	63
	NPK	0	12	7	30	49
	FYM	0	0	0	10	10
	TH	5	0	0	0	5

Legend: TH. - *Trichoderma harzianum*; FYM- Farmyard manure; TRT- Treatment

Table 14: Effect of NPK, *Trichoderma harzianum,* and Farmyard Manure on the Plant-parasitic Nematodes in Roots (5g) of Common Beans

TRIAL	TREATMENT	PPNs in ROOTS
1	Control	18^{ab}
	NPK	43^{a}
	FYM	0.14^{b}
	TH	0.00^{b}
2	Control	63^{a}
	NPK	49^{a}
	FYM	10^{b}
	TH	5^{b}
	Mean	23.56
	CV (%)	54.28
	$LSD_{(0.05)}$	19.02

Legend: TH - *Trichoderma harzianum*; FYM- Farmyard manure; TRT- Treatment
Means with the same letters within the column are not significantly different at (P <0.05).

As shown in Table 14 in trial one, control (43) was significantly different *(p<0.05)* from FYM (0.14) and TH (0.00). NPK (18) was not significantly different *(p>0.05)* (Appendix 74) from the control. *Trichoderma harzianum* and FYM significantly reduced plant-parasitic nematodes, showing suppression of PPNs in comparison to the control. In trial two, control (63) and NPK (49) were similar statistically but showed significant different *($p<0.05$)* (Appendix 75) from FYM (10) and TH (5). Control and NPK caused an increase in the number of PPNs, while *Trichoderma harzianum* and FYM reduced the numbers. The control treatment increased PPNs in the roots naturally because there were no amendments added to suppress PPNs. The NPK treatment encouraged plant growth, especially vigorous root growth, which provided feeding sites for PPNs, which increased the population of PPNs. Farmyard manure reduced plant-parasitic nematodes by encouraging free-living nematodes that suppress PPNs. *Trichoderma harzianum* suppressed PPNs through competition, parasitism, and producing nematicidical metabolites.

As presented in Table 13 in trial 1, NPK treatment had the highest number of PPNs (43) compared to control, which had 18, but FYM and *Trichoderma harzianum* did not have PPNs. In trial two, control treatment had the highest number of plant-parasitic nematodes (63), followed by NPK (49), then FYM (10), and *Trichoderma harzianum* treatment had (5). Farmyard manure and *Trichoderma harzianum* showed to have suppressed PPNs. Control treatment had the highest number of PPNs, especially in trial two, because there was no biotic suppression mechanism. For instance, in trial two, control treatment had *Tylenchus spp* (16), *Helicotylenchus spp* (5), *Rotylenchulus spp* (12), and *Pratylenchus spp* (30) compared to FYM, which had *Pratylenchus spp* (10), *Trichoderma harzianum* had *Tylenchus spp* (5). Control treatment made the roots of common beans highly susceptible to PPNs invasion. When nutrients are not added or microbial communities are not present, the defence mechanism is weakened, allowing plant-parasitic nematodes like *Tylenchus spp, Helicotylenchus spp, Rotylenchulus spp,* and *Pratylenchus spp* to thrive freely in the vascular tissues and root cortex (Abd-Elgawad, 2020). PPNs can result in lesions and root galling, hence interfering with the root function.

In trial two, NPK treatment was the second in terms of the number of PPNs. The NPK treatment increased PPNs in roots since it provided readily available nutrients for common bean growth, hence providing feeding sites and a conducive habitat for PPNs. Farmyard manure reduced the number of PPNs compared to the control treatment. For example, in trial one, the control treatment had *Helicotylenchus spp*

(18) compared to FYM, which did not have PPNs. This illustrated the role of FYM in protecting common bean roots. Farmyard manure improved the condition of the root zone by increasing populations of microbial antagonists, increasing root biomass, and creating an unconducive environment for egg hatching and PPNs' survival. *Trichoderma harzianum* had the lowest count of PPNs, with no PPNs in trial one and (5) in trial two, compared to the control, which had (18) in trial one and (63) in trial 2. *Trichoderma harzianum* colonized cortex tissues and root surfaces, producing enzymes and secondary metabolites that degrade PPN eggs as well as inhibit penetration by the juvenile. Moreover, *Trichoderma harzianum* competed for root space, hence making a protective barrier against invasion by nematodes.

These findings are consistent with those of Neher *et al*. (2010), who reported that *Trichoderma harzianum* also promoted healthier common bean root systems that tolerated infections. These findings are consistent with those of Deepali (2023), who reported that synthetic fertilizers provide feeding sites for PPNs. These findings are in line with those of Pinto *et al*. (2024), who determined that *Trichoderma sp* protects the roots from PPNs and also influences nematodes, i.e, fungivores. These findings comply with those of Kimenju *et al*. (2009), who reported that FYM also created microbial competition in the roots, hence leading to PPN suppression. In contrast to these findings, Lawal & Atungwu (2017) reported that NPK fertilizer increased plant-parasitic nematodes compared to the control treatment, while organic fertilizer suppressed PPNs.

CHAPTER FIVE

SUMMARY, CONCLUSION AND RECOMMENDATIONS

5.1 Summary of Findings

Objective one sought to describe the effects of NPK (23.23.0), *Trichoderma harzianum*, and Farmyard manure on Numbers, Evenness, and Species Diversity of Soil Nematodes under Common Beans. Looking at the number of plant-parasitic and free-living nematodes that were identified, *Trichoderma harzianum*, and Farmyard manure increased FLN. For example, in trial two, *Trichoderma harzianum* increased FLN from 406 (initial) to 412 (flowering stage) to 745 (final) while Farmyard manure increased from 456 (initial) to 831(flowering stage) to 1426 (final), in comparison to control and NPK, which reduced the number of FLN. For instance, in trial one, the control treatment reduced the number of FLN from 615 (initial) to 277 (flowering stage) to 156 (final), and NPK reduced from 459 (initial) to 188 (flowering stage) to 133 (final). Control and NPK led to an increase in plant-parasitic nematodes. For instance, in trial two, control increased PPNs from 477 (initial) to 520 (flowering stage) to 1068 (final), and NPK increased from 368 (initial) to 380 (flowering stage) to 724 (final). However, *Trichoderma harzianum* and Farmyard manure reduced the number of PPNs, which showed their suppressive effect on these nematodes. For instance, in trial two, FYM reduced the number of PPNs from 296 (initial) to 115 (flowering stage) to 48 (final), and *Trichoderma harzianum* reduced from 237 (initial) to 53 (flowering) to 9 (final).

Species diversity of soil nematodes was calculated using Shannon index of diversity and Simpson's index of diversity, while Pielou's index determined Evenness. *Trichoderma harzianum* increased the Shannon index of diversity of FLN, for instance, in trial one from 1.16 (initial) to 1.24 (final). In comparison, the control treatment reduced the Shannon index of diversity of FLN from 1.26 to 0.79 in trial one. *Trichoderma harzianum* increased the Simpson's diversity index of FLN from 0.67 (initial) to 0.73 (final) while the control reduced diversity from 0.53 (initial) to 0.54 (final) in trial two. *Trichoderma harzianum* had the highest Evenness of 0.91 in trial two, while the control had 0.82. Control and NPK increased the Shannon index of diversity and Simpson's index of diversity of PPNs. For instance, in trial one, control increased Shannon diversity of PPNs from 1.04 (initial) to 1.71 (final), and NPK increased from 0.99 (initial) to 1.41 (final). For example, in trial one, control increased Simpson's index of diversity from 0.56 (initial) to 0.78 (final), and NPK increased from 0.61 (initial) to 0.70 (final) while *Trichoderma harzianum* reduced from 0.66 (initial) to 0.25 (final). *Trichoderma harzianum* increased the Evenness of PPNs from 0.73 (initial) to 0.96 (final).

Objective two sought to describe the effect of NPK (23.23.0), *Trichoderma harzianum,* and farmyard manure on common beans' growth and yield components. Plant parameters which were measured were height, number of leaves, and number of leaves. The yield components were the number of pods, seeds, and yield. Biomass was also measured after harvesting beans. The NPK treatmet had the highest plant height, number of branches, and number of leaves while the control had the least across the growth period. For example, in trial two at 14 days after sowing, NPK had 16.25^{a} cm, FYM 13.25^{b} cm, *Trichoderma harzianum* 10.58^{c} cm, and control 8.08^{d} cm after conducting LSD, where alpha was 0.05. The results showed that there was a significant difference *($p<0.05$)* between the treatments. The NPK treatment also increased the number of pods, seeds, yield, and biomass. In trial one, the number of pods, NPK had 25.10^{a}, FYM 17.37^{b}, Trichoderma *harzianum* $11.33^{c,}$ and control 6^{d}. Number of seeds: NPK had 176.77^{a}, FYM 121.63^{b}, *Trichoderma harzianum* $64.90^{c,}$ and control 33.7^{d}. For grain yield: NPK had 3950.62^{a} kg/ha, FYM 2437.67^{b} kg/ha, *Trichoderma harzianum* 923.33^{c} kg/ha, and control 385.19^{c} kg/ha. Biomass; NPK had 1154.18^{a} kg/ha, FYM 714.67^{b} kg/ha, *Trichoderma harzianum* 361.01^{c} kg/ha, and control 189.59^{d} kg/ha. These results showed that there was a significant difference ($p<0.05$) between treatments.

Objective three described the effect of NPK (23.23.0), *Trichoderma harzianum,* and farmyard manure on plant-parasitic nematodes in the roots of common beans. The numbers of nodules in the roots of common beans were counted, with *Trichoderma harzianum* having the highest and NPK recording the lowest number of nodules. In trial two, *Trichoderma harzianum* had 60^{a}, FYM 32.89^{b}, control $17.67^{c,}$ and NPK 3.44^{d}. These results showed that there were significant differences ($p<0.05$) among the treatments. Plant-parasitic nematodes in the roots were identified and counted, where control and NPK increased the number of PPNs, while *Trichoderma harzianum* and FYM reduced their numbers. For instance, in trial one, NPK had the highest number of PPNs in the roots (43), while FYM and *Trichoderma harzianum* treatments did not have PPNs in the roots.

5.2 Conclusion

In conclusion, *Trichoderma harzianum* and FYM increased FLN abundance (Table 2) and reduced PPNs in the soil (Table 4). Farmyard manure and *Trichoderma harzianum* resulted in the highest overall nematode abundance of FLN, particularly increasing populations of *Dorylaimus* and *Bacterivores* (Table 1), indicating improved soil biological activity. Control and NPK increased the number of PPNs (Table 4) and reduced the FLN in soil (Table 2). *Trichoderma harzianum* applications increased free-living nematode diversity (Table 5) while stabilising or reducing plant-parasitic nematode diversity (Table 5). Control treatment increased the diversity of PPNs (Table 5) and decreased that of FLN (Table 5). The NPK treatment exhibited the highest values for plant parameters (Tables 7, 8, 9), yield components (Tables 10 and 11), and biomass (Table 11), with significant differences ($p<0.05$) from the other treatments. In contrast, the control had the lowest values for all these parameters. *Trichoderma harzianum* and FYM reduced PPNs in roots of common beans, while control and NPK increased the abundance of PPNs in roots (Table 14). *Trichoderma harzianum* had the highest number of nodules and showed a significant difference ($p<0.05$) from other treatments (Table 12). Overall, these results confirm that organic and biological amendments enhance soil nematode diversity, fertility, and productivity, contributing to sustainable bean cultivation.

5.3 Recommendation

The study recommends the following:

i. Integration of *Trichoderma harzianum* as a biological amendment to promote soil biodiversity and suppress plant-parasitic nematodes through natural competition and antagonism. Incorporating farmyard manure is highly recommended for promoting soil biological activity, enhancing nematode diversity, and improving soil health. Combining *Trichoderma harzianum* with organic amendments like FYM could balance soil fertility while enhancing biological control agents. Reliance on chemical fertilizers, such as NPK, should be reduced to prevent the suppression of free-living nematodes.

ii. Application of *Trichoderma harzianum* and FYM promotes soil health and increases growth and yield of common beans. Long-term use of FYM is the better option for soil health and yields. Low yields recorded by the control treatment showed that external inputs should be added to the soil.

iii. Continuous assessment of nematode communities over multiple growing seasons is essential to understand the long-term impacts of different soil amendments on diversity and crop productivity. Application of *Trichoderma harzianum* is recommended as it enhances root nodulation in common beans, thereby improving nitrogen fixation.

5.4 Suggestion for Further Studies

Further studies can be done on soil amendments that increase free-living nematodes, since they are able to suppress plant-parasitic nematodes and promote soil health and crop productivity.

REFERENCES

Abd-Elgawad, M. M. (2020). Plant-parasitic nematodes and their biocontrol agents: current status and future vistas. *Management of phytonematodes: recent advances and future challenges*, 171-203. https://doi.org/10.1007/978-981-15-4087-5_8

Adomako, J., Yeboah, S., Asamoah, J. F., P. Amankwaa-Yeboah, Adjei, E. A., Obeng, E. A., B. Sakyiamah, Lamptey, M., L. Butare, & J.Y. Asibuo. (2022). Survey of plant-parasitic nematodes and disease severity of common bean lines evaluated for reaction to root-knot nematodes infestation. *African Crop Science Journal*, *30*(2), 147–154. https://www.ajol.info/index.php/acsj/article/view/244969

Afzal, A., & Mukhtar, T. (2024). Revolutionizing nematode management to achieve global food security goals - An overview. *Heliyon*, *10*(3), e25325–e25325. https://doi.org/10.1016/j.heliyon.2024.e25325

Agrios,G.N.(2005). *Plantpathology*.Elsevier.https://books.google.co.ke/books?hl=en&lr=&id=CnzbgZgby60C&oi=fnd&pg=PP1&dq=Agrios

Akladious, S. A., & Abbas, S. M. (2014). Application of *Trichoderma harzianum* T22 as a biofertilizer potential in maize growth. Journal of Plant Nutrition, 37(1), 30-49. https://doi.org/10.1080/01904167.2013.829100

Alhrout, H. H., Akash, M. W., & Hejazin, R. K. (2018). Effect of farmyard manure and NPK on the yield and some growth components of tomato (Lycopersicum esculentum). *Research on Crops*, *19*(4), 655-658. http://dx.doi.org/10.31830/2348-7542.2018.0001.43

Ali, A., Hasham, P. M., & Naqibullah, N. (2023). Effects of Organic Fertilizer on Growth and Yield of Common Bean (Phaseolus vulgaris L). *AgroTech- Food Science, Technology and Environment*, *2*(2), 37–48. https://doi.org/10.53797/agrotech.v2i2.6.2023

Almeida, N. O., de Oliveira, C. M., Ulhoa, C. J., Côrtes, M. V. D. C. B., Júnior, M. L., & da Rocha, M. R. (2022). *Trichoderma harzianum* and *Trichoderma asperellum* are potential biocontrol agents of *Meloidogyne javanica* in banana cv. Grande Naine. Biological Control, 175, 105054. https://doi.org/10.1016/j.biocontrol.2022.105054

Andrassy, I. (2025). *Free-living nematodes from Albania, including the description of three new species*. Nematologia Mediterranea. https://journals.flvc.org/nemamedi/article/view/86990

Arley Rey Páez. (2023). Plant nematodes and their management. *IntechOpen EBooks*. https://doi.org/10.5772/intechopen.1002237

Atandi, J. G., Adamtey, N., Kiriga, A. W., Karanja, E. N., Musyoka, M. W., Matheri, F. M., ... & Haukeland, S. (2022). Organic maize and bean farming enhances free-living nematode dynamics in sub-Saharan Africa. *Agriculture, Ecosystems & Environment*, *327*, 107846. https://doi.org/10.1016/j.agee.2021.107846

Atandi, J. G., Haukeland, S., Kariuki, G. M., Coyne, D. L., Karanja, E. N., Musyoka, M. W., Fiaboe, K. K. M., Bautze, D., & Adamtey, N. (2017). Organic farming provides improved management of plant-parasitic nematodes in maize and bean cropping systems. *Agriculture, Ecosystems & Environment*, *247*(265-272.), 265–272. https://doi.org/10.1016/j.agee.2017.07.002

Basavaraj V., Sharada, M. S., Mahesh, H. M., & Sampathkumar, M. R. (2023). Survey for Root-Knot Nematode Infestation in Bean (Phaseolus vulgaris L.) Fields in Mysore District of Karnataka, India. *International Journal of Current Microbiology and Applied Sciences*, *12*(4), 63–70. https://doi.org/10.20546/ijcmas.2023.1204.007

Bebber, D. P., Holmes, T., & Gurr, S. J. (2014). The global spread of crop pests and pathogens. *Global Ecology and Biogeography*, *23*(12), 1398–1407. https://doi.org/10.1111/geb.12214

Bhatt, M. K., Labanya, R., & Joshi, H. C. (2019). Influence of long-term chemical fertilizers and organic manures on soil fertility-A review. Universal Journal of Agricultural Research, 7(5), 177-188. https://doi.org/10.13189/ujar.2019.070502

Bird, A. F., & Bird, J. (2012). The structure of nematodes. Academic Press. https://books.google.com/books?hl=en&lr=&id=w6t7rA0ckHAC&oi=fnd&pg=PP1&dq=Bird

Bünemann, E. K., Schwenke, G. D., & Van Zwieten, L. (2006). Impact of agricultural inputs on soil organisms—a review. *Soil Research*, *44*(4), 379-406. https://doi.org/10.1071/sr05125

Churamani Khanal. (2017). *Identification of Root-knot Nematodes (Meloidogyne spp.) of Arkansas using Molecular Diagnostics*. ScholarWorks@UARK. https://scholarworks.uark.edu/etd/2092/

Coulibaly, L., Thio, B., Collin, M., Kadidia Koita, Sanou, J., & Fernandez, D. (2025). Life cycle of the root-knot nematode Meloidogyne javanica in papaya and histological analyses of root infection and gall development. *Tropical Plant Pathology*, *50*(1). https://doi.org/10.1007/s40858-025-00723-2

Coyne, D.L., Nicol, J.M. & Claudius-Cole, B. (2014) Practical plant nematology: a field and laboratory guide. 2nd Edition. Systemwide Program on Integrated Pest Management Secretariat, International Institute of Tropical Agriculture, Cotonou, Benin. https://hdl.handle.net/10568/81172 d'Errico, G., Greco, N., Vinale, F., Marra, R., Stillittano, V., Davino, S. W., & D'Addabbo, T. (2022). Synergistic Effects of Trichoderma harzianum, 1, 3 Dichloropropene and Organic Matter in Controlling the Root-Knot Nematode *Meloidogyne incognita* on Tomato. Plants, 11(21), 2890. https://doi.org/10.3390/plants11212890

Dash, A., Rout, K. K., Mandal, M., & Singh, M. (2018). Effect of 11 years long term manorial practices on nematode population and diversity in rice agroecosystem. *Journal of Pharmacognosy and Phytochemistry*, *7*(5), 286-288. https://www.academia.edu/download/92558128/7-5-1-239.pdf

de Lima Gonilha, D. B., Santos, C. H. B., Frezarin, E. T., Siqueira, J. S., & Rigobelo, E. C. (2024). Biological Strategies to Minimize Fertilizer Use in Maize: Efficacy of Trichoderma harzianum and Bacillus subtilis. *Microbiology Research*, *15*(4), 2261–2273. https://doi.org/10.3390/microbiolres15040151

Deepali Chittora. (2023). Harmful Impact of Synthetic Fertilizers on Growing Agriculture and Environment. *Global Journal of Pharmacy & Pharmaceutical Sciences*, *11*(1). https://doi.org/10.19080/gjpps.2023.11.555804

Delfini, J., Moda-Cirino, V., dos Santos Neto, J., Ruas, P. M., Sant'Ana, G. C., Gepts, P., & Gonçalves, L. S. A. (2021). Population structure, genetic diversity and genomic selection signatures among a Brazilian common bean germplasm. Scientific reports, 11(1), 2964. https://doi.org/10.1038/s41598-021-82437-4

dos Santos Sousa, W., Soratto, R. P., Peixoto, D. S., Campos, T. S., Da Silva, M. B., Souza, A. G. V., ... & Gitari, H. I. (2022). Effects of Rhizobium inoculum compared with mineral nitrogen fertilizer on nodulation and seed yield of common bean. A meta-analysis. *Agronomy for Sustainable Development*, *42*(3), 52. https://doi.org/10.1007/s13593-022-00784-6

Duku, C., Groot, A., Demissie, T. D., Muhwanga, J., Nzoka, O., & Recha, J. W. M. (2020, March 12). *Common beans Kenya: Climate risk assessment*. Cgiar.org; CGIAR Research Program on Climate Change, Agriculture and Food Security.https://cgspace.cgiar.org/items/024025b9-668c-4698-b499-7257c9d85913

Eisenback, J. D., & Hunt, D. J. (2009). General morphology. In Root-knot nematodes (pp. 18-54). Wallingford United Kingdom: Centre for Agriculture and Bioscience International. https://doi.org/10.1079/9781845934927.0018

Elkelany, U., Hammam, M., El-Nagdi, W., & Abd-El-Khair, H. (2021). Field application of *Trichoderma spp*. for controlling the root-knot nematode, *Meloidogyne javanica* in peanut plants. *Egyptian Journal of Agronematology*, *20*(2), 85-100. https://doi.org/10.21608/ejaj.2021.183249

El-Nagdi, W. M., Youssef, M. M., El-Khair, H. A., & Abd-Elgawad, M. M. (2019). Effect of certain organic amendments and Trichoderma species on the root-knot nematode, *Meloidogyne incognita*, infecting pea (Pisum sativum L.) plants. *Egyptian Journal of Biological Pest Control*, *29*, 1-9. https://doi.org/10.1186/s41938-019-0182-0

El-Yazal, M. A. S. (2020). Impact of some organic manure with chemical fertilizers on growth and yield of broad bean (Vicia faba L.) grown in newly cultivated land. Sustainable Food Production, 9, 23-36. https://doi.org/10.18052/www.scipress.com/sfp.9.23

Eman, Awad-Allah F.A.; Mohamed, Ibrahim A.A.;Allah, Sherin F.A. Awd;Shams, Amany H.M.;Elsokkary, & Ibrahim H. (2023). Trichoderma species: An overview of current status and potential applications for sustainable agriculture. *Indian Journal of Agricultural Research*, *57*(3), 273–282. https://www.indianjournals.com/ijor.aspx?target=ijor:ijar2&volume=57&issue=3&article=001

Eves-van den Akker, S. (2021). Plant–nematode interactions. Current Opinion in Plant Biology, 62, 102035. https://doi.org/10.1016/j.pbi.2021.102035

Fan, Y., Gao, D., Zhang, L., Wang, Y., Yan, Z., Guo, L., & Qiao, Y. (2025). Enhancing soil quality and nematode diversity through sustainable tillage and organic fertilization in the Loess Plateau's semi-arid farmlands. *Agriculture, Ecosystems & Environment*, *383*, 109542. https://doi.org/10.1016/j.agee.2025.109542

FAOSTAT (2019), "Crops- Beans, dry production quantity, years 1988 to 2017- Export and import quantities, years 2012 to 2016; Food supply quantity, bean, kg/capita, year 2013",FAO Statistics Database, Food and Agriculture Organisation of United Nations (FAO)

Faridah, H.I. & Van der Maesen, L.J.G., 1997. Plant resources of Southeast Asia, No. 11. Auxiliary Plants. Backhuys Publishers, Leiden. The Netherlands, 389 pp. https://doi.org/10.2307/4114528

Farrow, A., & Muthoni Andriatsitohaina, R. (2020). Atlas of common bean production in Africa. International Center for Tropical Agriculture Publication. https://doi.org/10.7910/DVN/8W0QK7

Ferris, H., Bongers, T., & de Goede, R. G. (2001). A framework for soil food web diagnostics: extension of the nematode faunal analysis concept. *Applied soil ecology*, *18*(1), 13-29. https://doi.org/10.1016/s0929-1393 (01)00152-4

Ferris, H., Pocasangre, L. E., Serrano, E., Muñoz, J., Garcia, S., Perichi, G., & Martinez, G. (2012). Diversity and complexity complement apparent competition: nematode assemblages in banana plantations. *Acta oecologica*, *40*, 11-18. https://doi.org/10.1016/j.actao.2012.02.003

Fourie, H., Spaull, V. W., Jones, R. K., Daneel, M. S., & De Waele, D. (Eds.). (2017). *Nematology in South Africa: a view from the 21st century* (pp. 201-230). Springer International Publishing. https://doi.org/10.1007/978-3-319-44210-5

Gaut, B. S. (2014). The complex domestication history of the common bean. *Nature Genetics*, *46*(7), 663–664. https://doi.org/10.1038/ng.3017

Ghazanfar, M. U., Raza, M., Raza, W., & Qamar, M. I. (2018). Trichoderma as potential biocontrol agent, its exploitation in agriculture: a review. *Plant Protection*, *2*(3). http://esciencepress.net/journals/PP

Giada d'Errico, Greco, N., Vinale, F., Marra, R., Stillittano, V., Davino, S. W., Woo, S. L., & Trifone D'Addabbo. (2022). Synergistic Effects of *Trichoderma harzianum*, 1,3 Dichloropropene and Organic Matter in Controlling the Root-Knot Nematode *Meloidogyne incognita* on Tomato. *Plants*, *11*(21), 2890–2890. https://doi.org/10.3390/plants11212890

Gupta, S. K., & Singh, G. (2020). Major fungal French bean diseases: epidemiology and management. In *Emerging trends in plant pathology* (pp. 141-174). Singapore: Springer Singapore. https://doi.org/10.1007/978-981-15-6275-4_7

Hailu, F. A., & Hailu, Y. A. (2020). Agro-ecological importance of nematodes (round worms). *Acta Scientific Agriculture*, *4*(1), 156-162. https://doi.org/ 10.31080/ASAG.2020.04.agro-ecological-importance-of-nematodes-roundworms

Halifu, S., Deng, X., Song, X., & Song, R. (2019). Effects of two Trichoderma strains on plant growth, rhizosphere soil nutrients, and fungal community of Pinus sylvestris var. mongolica annual seedlings. *Forests*, *10*(9), 758. https://doi.org/10.3390/f10090758

Hamida, A., Ameen, H. H., Mohamed, M. M., & Alkelany, U. S. (2015). Effect of integrating inorganic fertilizer with either micronema, compost, or oxamyl on suppressing plant-parasitic nematode *Meloidogyne incognita* infecting tomato plants under field conditions. *Middle East Journal of Agriculture Research*, *4*(4), 707-711. https://www.curresweb.com/mejar/mejar/2015/707-711.pdf

Harman, G. E., Howell, C. R., Viterbo, A., Chet, I., & Lorito, M. (2004). *Trichoderma species*—opportunistic, avirulent plant symbionts. *Nature reviews microbiology*, *2*(1), 43-56. https://doi.org/10.1038/nrmicro797

Hooper, D. J., Hallmann, J., & Subbotin, S. A. (2005). Methods for extraction, processing and detection of plant and soil nematodes. In Plant-parasitic nematodes in subtropical and tropical agriculture (pp. 53-86). Wallingford United Kingdom: Centre for Agriculture Bioscience International Publishing. https://doi.org/10.1079/9780851997278.0053

Hossain, S., & Akter, F. (2020). Effects of Trichoderma-enriched biofertilizer and farmyard manure on the growth and yield of brinjal (Solanum melongena L.). *Dhaka University Journal of Biological Sciences*, *29*(1), 1–8. https://doi.org/10.3329/dujbs.v29i1.46525

Hu, C., Xia, X. G., Han, X. M., Chen, Y. F., Qiao, Y., Liu, D. H., & Li, S. L. (2018). Soil nematode abundances were increased by an incremental nutrient input in a paddy-upland rotation system. *Helminthologia*, *55*(4), 322. https://doi.org/10.2478/helm-2018-0025

Indarti, S., Taryono, T., Purnomo, C. W., Wulandari, A. S., & Maharani, R. (2023). Abundance and diversity of plant-parasitic nematodes associated with vegetable cultivation on various types of organic fertilizers. Biodiversitas Journal of Biological Diversity,24(2). https://doi.org/10.3923/jps.%202015.234.243

Ingham, R. E., Trofymow, J. A., Ingham, E. R., & Coleman, D. C. (1985). Interactions of bacteria, fungi, and their nematode grazers: effects on nutrient cycling and plant growth. *Ecological monographs*, *55*(1), 119-140. https://doi.org/10.2307/1942528

Jaetzold, R., Schmidt, H., Hornetz, B. & Shisanya, C. (2006) Farm Management Handbook of Kenya. Vol. II—Natural Conditions and Farm Management Information—2nd Edition Central Province. II. Ministry of Agriculture, Kenya, in Cooperation with the German Agency for Technical Cooperation (GTZ).

Khan, Muhammad Imran, Muhammad Junaid Afzal, Safdar Bashir, Muhammad Naveed, Sara Anum, Sardar Alam Cheema, Abdul Wakeel, Muhammad Sanaullah, Muhammad Hayder Ali, & Zhongbing Chen. "Improving nutrient uptake, growth, yield and protein content in chickpea by the co-addition of phosphorus fertilizers, organic manures, and bacillus sp. Mn-54." *Agronomy* 11, no. 3 (2021): 436. https://doi.org/10.3390/agronomy11030436

Kim, B. R., Shin, J., Guevarra, R. B., Lee, J. H., Kim, D. W., Seol, K. H., ... & Isaacson, R. E. (2017). Deciphering diversity indices for a better understanding of microbial communities. *Journal of microbiology and biotechnology*, *27*(12), 2089-2093. https://doi.org/10.4014/jmb.1709.09027

Kimenju, J. W., Karanja, N. K., & Macharia, I. (1999). Plant-parasitic nematodes associated with common bean in Kenya and the effect of Meloidogyne infection on bean nodulation. https://doi.org/1021-9730

Kimenju, J. W., Karanja, N. K., Mutua, G. K., Rimberia, B. M., & Wachira, P. M. (2009). Nematode community structure as influenced by land use and intensity of cultivation. *Tropical and subtropical agroecosystems*, *11*(2), 353-360. https://www.redalyc.org/pdf/939/93913057011.pdf

Kiontke, K., & Fitch, D. H. A. (2013). Nematodes. *Current Biology*, *23*(19), R862–R864. https://doi.org/10.1016/j.cub.2013.08.009

Konopiński, M. K. (2020). *Shannon diversity index: a call to replace the original Shannon's formula with unbiased estimator in the population genetics studies. PeerJ 8: e9391*. https://doi.org/10.7717/peerj.9391

Krif, G., Mokrini, F., Aissami, A. E., Laasli, S.-E., Imren, M., Özer, G., Paulitz, T., Lahlali, R., & Dababat, A. A. (2020). Diversity and Management Strategies of Plant-parasitic Nematodes in Moroccan Organic Farming and Their Relationship with Soil Physico-Chemical Properties. *Agriculture*, *10*(10), 447. https://doi.org/10.3390/agriculture10100447

Kumar, Y., & Yadav, B. C. (2020). Plant-parasitic nematodes: Nature's most successful plant parasite. International journal of research and review, 7(3), 379-386.https://www.researchgate.net/profile/Yogendra-Kumar-39/publication/371033903_Plant-Parasitic_Nematodes_Nature

Lawal, R. O., & Atungwu, J. J. (2017). *Effect of indigenous organic fertilizers in plant-parasitic nematodes control and yield improvement in soyabean fields*. *27*(1 & 2), 69–75. https://www.researchgate.net/publication/363516938_Effect_of_indigenous_organic_fertilizers_in_plant-parasitic_nematodes_control_and_yield_improvement_in_soyabean_fields

Lazarova, S., Coyne, D., Rodriguez, M. G., Peteira, B., & Ciancio, A. (2021). Functional diversity of soil nematodes in relation to the impact of agriculture—a review. Diversity, 13(2), 64. https://doi.org/10.3390/d13020064

Lee, D. L. (Ed.). (2002). The biology of nematodes. Chemical Rubber Company Press.

Li, J., Peng, P., & Zhao, J. (2020). Assessment of soil nematode diversity based on different taxonomic levels and functional groups. *Soil Ecology Letters*, *2*, 33-39. https://doi.org/10.1007/s42832-019-0019-5

Li, X., Liu, T., Li, H., Geisen, S., Hu, F., & Liu, M. (2022). Management effects on soil nematode abundance differ among functional groups and land-use types at a global scale. *Journal of Animal Ecology*, *91*(9), 1770-1780. https://doi.org/10.1111/1365-2656.13744

Lisciani, S., Marconi, S., Cinzia Le Donne, Camilli, E., Altero Aguzzi, Gabrielli, P., Gambelli, L., Kunert, K., Marais, D., Barend Juan Vorster, Alvarado-Ramos, K., Reboul, E., Cominelli, E., Preite, C., Sparvoli, F., Losa, A., Sala, T., Botha, A.-M., & Ferrari, M. (2024). Legumes and common beans in sustainable diets: nutritional quality, environmental benefits, spread and use in food preparations. *Frontiers in Nutrition*, *11*(1385232). https://doi.org/10.3389/fnut.2024.1385232

Lu, Q., Liu, T., Wang, N., Dou, Z., Wang, K., & Zuo, Y. (2020). A review of soil nematodes as biological indicators for the assessment of soil health. *Frontiers of Agricultural Science and Engineering*, *7*, 275-281. https://doi.org/10.15302/j-fase-2020327

Luc, M., Hunt, D. J., & Machon, J. E. (1990). Morphology, anatomy and biology of plant-parasitic nematodes-a synopsis. https://www.cabidigitallibrary.org/doi/full/10.5555/19901182750

Maggenti, A. R. (2020). General nematode morphology. In *Manual of agricultural nematology* (pp. 3-46). https://doi.org/10.1201/9781003066576-1

Mahmoodian, S., Motallebi, M., Zamani, M., & Jahromi, Z. M. (2022). Effect of Improved *Trichoderma harzianum* on Growth and Resistance Promotion in Bean Plant. Brazilian Archives of Biology and Technology, 65. e22210671 https://doi.org/10.1590/1678-4324-2022210671

Mai, W. (2018). *Plant-parasitic nematodes: a pictorial key to genera*. Cornell University Press.

Maina, S., Karuri, H., & Mugweru, J. (2022). Nematode diversity and its association with soil properties in monocrop pigeon pea. *Journal of Agriculture and Food Research*, *9*, 100336. https://doi.org/10.1016/j.jafr.2022.100336

Maina, S., Karuri, H., & Ng'endo, R. N. (2021). Free-living nematode assemblages associated with maize residues and their ecological significance. *Journal of nematology*, *53*(1), 1-12. https://doi.org/10.21307/jofnem-2021-038

Maina, S., Karuri, H., & Ng'endo, R. N. (2020). Nematode metabolic footprints, ecological and functional indices in tropical maize-beans agro-ecosystems under different farming practices. Acta Oecologica, 108, 103622. https://doi.org/10.1016/j.actao.2020.103622

Mangole G, Ithuteng M, Radikgomo M, & Molosiwa O.O. (2022). Challenges and opportunities in common bean production and marketing in Botswana: Prospects and farmer's perspectives. *African Journal of Food, Agriculture, Nutrition and Development*, *22*(5), 20461–20479. https://www.ajol.info/index.php/ajfand/article/view/231149

Marais, E., Maggs-Kölling, G., Sherman, C., Doniger, T., Liu, R., Tripathi, B. M., & Steinberger, Y. (2020). Profiling soil free-living nematodes in the Namib Desert, Namibia. *Journal of Arid Land*, *12*, 130-143. https://doi.org/10.1007/s40333-019-0018-5

Marais, M., Swart, A., Fourie, H., Berry, S. D., Knoetze, R., & Malan, A. P. (2017). Techniques and procedures. *Nematology in South Africa: a view from the 21st century*, 73-117. https://doi.org/10.1007/978-3-319-44210-5_4

Maruyama, C. R., Bilesky-José, N., de Lima, R., & Fraceto, L. F. (2020). Encapsulation of *Trichoderma harzianum* preserves enzymatic activity and enhances the potential for biological control. Frontiers in bioengineering and biotechnology, 8, 225. https://doi.org/10.3389/fbioe.2020.00225

Mataa, M., Kalima, P., & Lungu, D. (2021). Morphophysiological Responses of Common Bean (Phaseolus vulgaris L.) Genotypes to Water Stress. *University of Zambia Journal of Agricultural and Biomedical Sciences*, *5*(1) , 1–17. https://doi.org/10.53974/unza.jabs.5.1.611

Mathobo, R., & Mathobo, N. (2024). Trend analysis of dry bean production, yield, consumption, import and export in South Africa from 1970 to 2019. *Journal of Agribusiness and Rural Development*, (3 [73]). https://doi.org/10.17306/j.jard.2024.01802

Mekete, T., Dababat, A. A., Sekora, N., Akyazi, F., & Abebe, E. (2012). *Identification key for agriculturally important plant-parasitic nematodes: a manual for nematology*. International Maize and Wheat Improvement Center.

Meza, P., Soto, B., Rojas, L., & Esmenjaud, D. (2016). Identification of *Meloidogyne* Species from the Central Valley of Chile and Interaction with Stone Fruit Rootstocks. *Plant Disease*, *100*(7), 1358–1363. https://doi.org/10.1094/pdis-11-15-1331-re

Mkandawire, T. T., Grencis, R. K., Berriman, M., & Duque-Correa, M. A. (2021). Hatching of Parasitic Nematode eggs: a Crucial Step Determining Infection. *Trends in Parasitology*, *38*(2) 174-187. https://doi.org/10.1016/j.pt.2021.08.008

Mndzebele, B., Ncube, B., Fessehazion, M., Mabhaudhi, T., & Modi, A. T. (2023). Assessment of the effects of NPK fertilizer on edible yield and agro-biological parameters in a cowpea–amaranth intercrop. *Frontiers in sustainable food systems*, *7*, 1210984. https://doi.org/10.3389/fsufs.2023.1210984

Moosavi, M. R. (2022). Potential of soil amendment with organic matters in controlling phytonematodes. In New and Future Developments in Microbial Biotechnology and Bioengineering (pp. 315-344). Elsevier. https://doi.org/10.1016/b978-0-323-85579-2.00009-5

Morales, F. J. (2006). Common beans. Natural resistance mechanisms of plants to viruses, 367-382.

Mukhtar, T., Tariq-Khan, M., & Aslam, M. N. (2021). Bioefficacy of Trichoderma species against javanese root-knot nematode, *Meloidogyne javanica*, in green gram. *Gesunde Pflanzen*, *73*(3), 265-272.https://doi.org/10.1007/s10343-021-00544-8

Mulder, C. P., Bazeley-White, E., Dimitrakopoulos, P. G., Hector, A., Scherer-Lorenzen, M., & Schmid, B. (2004). Species evenness and productivity in experimental plant communities. *Oikos*, *107*(1), 50-63 http://dx.doi.org/10.1111/j.0030-1299.2004.13110.x

Mwaniki, A. W. (2002). Assessment of bean production constraints and seed quality and health of improved common bean seed (Doctoral dissertation, University of Nairobi). http://erepository.uonbi.ac.ke:8080/xmlui/handle/123456789/20143

Mweetwa, A. M., Chilombo, G., & Gondwe, B. M. (2016). Nodulation, nutrient uptake and yield of common bean inoculated with Rhizobia and Trichoderma in an acid soil. *J. Agric. Sci*, *8*(12), 61-71. http://dx.doi.org/10.5539/jas.v8n12pxx

Nadeem, M. A., Yeken, M. Z., Shahid, M. Q., Habyarimana, E., Yılmaz, H., Alsaleh, A., & Baloch, F. S. (2021). Common bean as a potential crop for future food security: an overview of past, current and future contributions in genomics, transcriptomics, transgenics and proteomics. *Biotechnology & Biotechnological Equipment*, *35*(1), 759-787. http://dx.doi.org/10.1080/13102818.2021.1920462

Naluzze, E. (2022). *Assessing the effects of NPK fertilizer and cow dung on yield and yield component of common beans (Phaseolus vulgaris)* (Doctoral dissertation, Makerere University).

Nderitu, J. H. Buruchara, R A. & Ampolo, J. K. 1997. Relationship between beans stem maggot, bean root rot and soil fertility. Technical report series No. 4 African Highland Initiative Nairobi. 16p. https://www.cifor-icraf.org/knowledge/publication/29583

Neher, D. A. (2001). Role of nematodes in soil health and their use as indicators. *Journal of nematology*, *33*(4), 161.

Neher, D. A. (2010). Ecology of plant and free-living nematodes in natural and agricultural soil. *Annual review of phytopathology*, *48*(1), 371-394. https://pmc.ncbi.nlm.nih.gov/articles/PMC2620512/

Nigatie, T. Z. (2021). Review on effect of N and P fertilizer rates on yield and yield components of common bean [Phaseolus vulgaris (L.)] varieties. *International Journal of Research in Agronomy*, *4*, 32-40. https://doi.org/10.33545/2618060X.2021.v4.i1a.46

Nisa, R. U., Tantray, A. Y., Kouser, N., Allie, K. A., Wani, S. M., Alamri, S. A., ... & Shah, A. A. (2021). Influence of ecological and edaphic factors on biodiversity of soil nematodes. *Saudi journal of biological sciences*, *28*(5), 3049-3059. https://doi.org/10.1016/j.sjbs.2021.02.046

Obsa, G. C. Z. (2017). Effect of organic and inorganic fertilizers on growth, yield and yield components of Chick Pea (Cicerarietinum) and enhancing soil chemical properties on vertisols at ginchi, central highlands of Ethiopia *7*(23). https://core.ac.uk/download/pdf/234662474.pdf

Oka, Y. (2010). Mechanisms of nematode suppression by organic soil amendments—A review. *Applied Soil Ecology*, *44*(2), 101–115. https://doi.org/10.1016/j.apsoil.2009.11.003

Oka, Y., Koltai, H., Bar-Eyal, M., Mor, M., Sharon, E., Chet, I., & Spiegel, Y. (2000). New strategies for the control of plant-parasitic nematodes. Pest Management Science: formerly Pesticide Science, 56(11), 983-988. https://doi.org/10.1002/1526-4998(200011)56:11%3C983::AID-PS233%3E3.0.CO;2-X

Olabiyi, T. I., Ojo, O. J., & Adewuyi, B. O. (2016). Impact assessment of neem compost and *Trichoderma harzianum* solution in the control of root knot nematode disease on cowpea. *Cogent Food & Agriculture*, *2*(1), 1207843. https://doi.org/10.1080/23311932.2016.1207843

Onyango, P. (2022). Making the Bean Corridor Work: Lessons from Tanzania. https://www. pabra-africa. org/making-the-bean-corridor-work-lessons-from-tanzania/. Accesses *February, 15*, 2023.

Otieno, P. E., Muthomi, J. W., Chemining'wa, G. N., & Nderitu, J. H. (2009). Effect of rhizobia inoculation, farmyard manure and nitrogen fertilizer on nodulation and yield of food grain legumes. http://dx.doi.org/10.3923/jbs.2009.326.332

Otsyula, R. M., Ajanga, S. I., Buruchara, R. A. & Wortmann, C. S. 1998. Development of an integrated bean root rot control strategies for Western Kenya. African Crop Science Journal 6:61-67. https://www.cabidigitallibrary.org/doi/full/10.5555/20001004604

Páez, A. R. (2023). Plant-Parasitic Nematodes and Their Management: A Focus on New Nematicides. In *Nematodes-Ecology, Adaptation and Parasitism*. IntechOpen. https://doi.org/10.5772/intechopen.1002237

Pahalvi, H. N., Rafiya, L., Rashid, S., Nisar, B., & Kamili, A. N. (2021). Chemical fertilizers and their impact on soil health. Microbiota and Biofertilizers, Vol 2: Ecofriendly Tools for Reclamation of Degraded Soil Environs, 1-20. https://link.springer.com/chapter/10.1007/978-3-030-61010-4_1

Pani, S., Kumar, A., & Sharma, A. (2021). *Trichoderma harzianum*: An overview. *Bulletin of Environment, Pharmacology and Life Science*, *10*(6), 32-39.

Pereira, J. L., Queiroz, R. M., Charneau, S. O., Felix, C. R., Ricart, C. A., da Silva, F. L., ... & Noronha, E. F. (2014). Analysis of Phaseolus vulgaris response to its association with Trichoderma harzianum (ALL-42) in the presence or absence of the phytopathogenic fungi Rhizoctonia solani and Fusarium solani. *Plos one*, *9*(5), e98234.https://doi.org/10.1371/journal.pone.0098234

Perry, R. N., & Clarke, A. J. (1981). Hatching mechanisms of nematodes. *Parasitology*, *83*(2), 435–449. https://doi.org/10.1017/s0031182000085413

Perry, R. N., & Moens, M. (2011). Introduction to Plant-Parasitic Nematodes; Modes of Parasitism. *Genomics and Molecular Genetics of Plant-Nematode Interactions*, *3-20*, 3–20. https://doi.org/10.1007/978-94-007-0434-3_1

Perry, R. N., Moens, M., & Starr, J. L. (2009). *Root-knot nematodes* (pp. xxvi+-488). https://doi.org/10.1079/9781845934927.0000

Pinto, A. G., Kos, T., Puškarić, J., Vrandečić, K., Benković-Lačić, T., & Brmež, M. (2024). Soil Ecosystem Functioning through Interactions of Nematodes and Fungi Trichoderma sp. *Sustainability*, *16*(7), 2885. https://doi.org/10.3390/su16072885

Porch, T. G., Beaver, J. S., Debouck, D. G., Jackson, S., Kelly, J. D., & Dempewolf, H. (2013). Use of wild relatives and closely related species to adapt common bean to climate change. Agronomy, 3(2), 433-461.recent developments and applications. Federation of European Microbiological Societies microbiology letters, 278(1), 1-9. https://doi.org/10.3390/agronomy3020433

Poveda, J., Abril-Urias, P., & Escobar, C. (2020). Biological Control of Plant-Parasitic Nematodes by Filamentous Fungi Inducers of Resistance: Trichoderma, Mycorrhizal and Endophytic Fungi. *Frontiers in Microbiology*, *11*(992). https://doi.org/10.3389/fmicb.2020.00992

Puissant, J., Villenave, C., Chauvin, C., Plassard, C., Blanchart, E., & Trap, J. (2021). Quantification of the global impact of agricultural practices on soil nematodes: a meta-analysis. *Soil Biology and Biochemistry*, *161*, 108383. https://doi.org/10.1016/j.soilbio.2021.108383

Qi, Y., Sun, X., Peng, S., Tan, X., & Zhou, S. (2023). Effects of fertilization on soil nematode communities in an alpine meadow of Qinghai-Tibet plateau. *Frontiers in Ecology and Evolution*, *11*(1122505). https://doi.org/10.3389/fevo.2023.1122505

Raihan, M. S. H., Islam, M. S., Islam, M. M., Khan, R. N. A., & Hossain, B. (2021). Impacts of organic and inorganic fertilizers on growth and yield of country bean (Lablab purpureus l.) In summer season. Bangladesh Journal of Multidisciplinary Scientific Research, 3(1), 1-9. https://doi.org/10.46281/bjmsr.v3i1.890

Raksun, A., Merta, I. W., Ilhamdi, M. L., & Mertha, G. (2022). The effect of vermicompost and NPK fertilizer on growth of long beans (Vigna sinensis L.). *Jurnal Penelitian Pendidikan IPA*, *8*(4), 2051-2056. https://doi.org/10.29303/jppipa.v8i4.2056

Ridall, A., & Ingels, J. (2021). Suitability of free-living marine nematodes as bioindicators: Status and future considerations. *Frontiers in Marine Science*, *8*, 685327. https://doi.org/10.3389/fmars.2021.685327

Rigobelo, E. C., de Andrade, L. A., Santos, C. H. B., Frezarin, E. T., Sales, L. R., de Carvalho, L. A. L., ... & Desoignies, N. (2024). Effects of Trichoderma harzianum and Bacillus subtilis on the root and soil microbiomes of the soybean plant INTACTA RR2 PRO™. *Frontiers in Plant Science*, *15*, 1403160. https://doi.org/10.3389/fpls.2024.1403160

Rodríguez De Luque, J. J., & Creamer, B. (2014). Principal constraints and trends for common bean production and commercialization; establishing priorities for future research. *Agronomia colombiana*, *32*(3), 423-431. https://doi.org/10.15446/agron.colomb.v32n3.46052

Roul, T. K., Panda, M. R., Mohanty, B., Sardar, K. K., Dehuri, M., Hembram, A., & Mohapatra, T. (2017). Effects of commonly used chemical fertilizers on development of free-living stages of Haemonchus contortus in experimentally infected pasture. *Veterinary World*, *10*(7), 764. https://doi.org/10.14202/vetworld.2017.764-768

Rurangwa, E., Vanlauwe, B., & Giller, K. E. (2018). Benefits of inoculation, P fertilizer and manure on yields of common bean and soybean also increase yield of subsequent maize. *Agriculture, Ecosystems & Environment*, *261*, 219-229.

Sánchez-Moreno, S., & Ferris, H. (2018). Nematode ecology and soil health. In Plant-parasitic nematodes in subtropical and tropical agriculture (pp. 62-86). Wallingford United Kingdom: Centre for Agriculture and Bioscience International. https://doi.org/10.1079/9781786391247.0062

Sasanelli, N., Konrat, A., Migunova, V., Toderas, I., Iurcu-Straistaru, E., Rusu, S., & Veronico, P. (2021). Review on control methods against plant-parasitic nematodes applied in southern member states (C Zone) of the European Union. Agriculture, 11(7), 602. https://doi.org/10.3390/agriculture11070602

Schratzberger, M., Holterman, M., van Oevelen, D., & Helder, J. (2019). A worm's world: Ecological flexibility pays off for free-living nematodes in sediments and soils. *BioScience*, *69*(11), 867-876. https://doi.org/10.1093/biosci/biz120

Semenov, M. V., Krasnov, G. S., Semenov, V. M., Ksenofontova, N., Zinyakova, N. B., & van Bruggen, A. H. (2021). Does fresh farmyard manure introduce surviving microbes into soil or activate soil-borne microbiota? Journal of Environmental Management, 294, 113018. https://doi.org/10.1016/j.jenvman.2021.113018

Shadrack, C. K., Samuel, M. M., & John, O. O. (2021). The effect of multi-component fertilizer and lime application on yield of common bean in Western Kenya. African Journal of Agricultural Research, 17(1), 112-117. https://doi.org/10.5897/ajar2020.15206

Sharon, E., Chet, I., & Spiegel, Y. (2011). Trichoderma as a biological control agent. *Biological control of plant-parasitic nematodes: building coherence between microbial ecology and molecular mechanisms*, 183-201. https://doi.org/10.1007/978-1-4020-9648-8_8

Sikora, R. A., & Roberts, P. A. (2018). Management practices: an overview of integrated nematode management technologie. *Plant-parasitic nematodes in subtropical and tropical agriculture*, 795-838. https://doi.org/10.1079/9781786391247.0795

Singh, J., Bhatt, R., Dhillon, B. S., Al-Huqail, A. A., Alfagham, A., Siddiqui, M. H., & Kumar, R. (2022). Integrated use of phosphorus, farmyard manure and biofertilizer improves the yield and phosphorus uptake of black gram in silt loam soil. Plos one, 17(4), e0266753. https://doi.org/10.1371/journal.pone.0266753

Singh, N. K., Sachan, K., Bp, M., Panotra, N., & Katiyar, D. (2024). Building soil health and fertility through organic amendments and practices: a review. *Asian Journal of Soil Science and Plant Nutrition*, *10*(1), 175-197. https://doi.org/10.9734/AJSSPN/2024/v10i1224

Singh, S., & Schwartz, H. (2011). Review: Breeding common bean for resistance to insect pests and nematodes. *Canadian Journal of Plant Science*, *91*(2), 239–250. https://doi.org/10.4141/cjps10002

Sofo, A., Milella, L., & Tataranni, G. (2010). Effects of Trichoderma harzianum strain T-22 on the growth of two Prunus rootstocks during the rooting phase. *The Journal of Horticultural Science and Biotechnology*, *85*(6), 497-502. https://doi.org/10.1080/14620316.2010.11512704

Sulieman, S. A., & Hago, T. E. (2009). The effects of phosphorus and farmyard manure on nodulation and growth attributes of common bean (Phaseolus vulgaris L.) in Shambat soil under irrigation.

Tadesse, T., & Abera, T. (2023). Effect of different level of farmyard manure on the growth, yield and yield components of haricot bean (Phaseolus vulgaris L.) at adancho condition, Kambata Tembaro Zone, Southern Ethiopia. *Journal of Biodiversity and Environmental Sciences (JBES)*, *23*(6), 56–67. https://innspub.net/wp-content/uploads/2024/02/JBES-V23-No6-p56-67.pdf

Talwana, H., Sibanda, Z., Wanjohi, W., Kimenju, W., Luambano-Nyoni, N., Massawe, C., & Kerry, B. R. (2016). Agricultural nematology in East and Southern Africa: problems, management strategies and stakeholder linkages. *Pest Management Science*, *72*(2), 226-245. https://doi.org/10.1002/ps.4104

TariqJaveed, M., Farooq, T., Al-Hazmi, A. S., Hussain, M. D., & Rehman, A. U. (2021). Role of Trichoderma as a biocontrol agent (BCA) of phytoparasitic nematodes and plant growth inducer. Journal of Invertebrate Pathology, 183, 107626. https://doi.org/10.1016/j.jip.2021.107626

Termorshuizen, A., Korthals, G., & Thoden, T. (2011). Organic amendments and their influences on plant-parasitic and free-living nematodes: a promising method for nematode management? *Nematology*, *13*(2), 133–153. https://doi.org/10.1163/138855410x541834

Thoden, T. C., Korthals, G. W., & Termorshuizen, A. J. (2011). Organic amendments and their influences on plant-parasitic and free-living nematodes: a promising method for nematode management? *Nematology*, *13*(2), 133-153. https://doi.org/10.1163/138855410x541834

Triantaphyllou, A. C., & Hirschmann, H. (1964). Reproduction in Plant and Soil Nematodes. Annual Review of Phytopathology, 2(1), 57–80. https://doi.org/10.1146/annurev.py.02.090164.000421

Tyśkiewicz, R., Nowak, A., Ozimek, E., & Jaroszuk-Ściseł, J. (2022). Trichoderma: The Current Status of Its Application in Agriculture for the Biocontrol of Fungal Phytopathogens and Stimulation of Plant Growth. *International Journal of Molecular Sciences*, *23*(4), 2329. https://doi.org/10.3390/ijms23042329

Uddin, S. N., Zakaria, M., Hossain, M. M., Hossain, T., & Sirajul, A. J. M. (2023). Effect of NPK Fertilizers on Growth, Yield and Nutritional Quality of Garden Pea. *International Journal*, *3*(1), 1-6. https://ijacr.net/article/38/details

Upenji, R. (2020). Improve common bean (phaseolus vulgaris l.) yield through cattle manure in nioka region, ituri province, drc. *Open Access Library Journal*, *7*(09), 1. https://doi.org/10.4236/oalib.1106610

Van Bezooijen, J. (2006). *Methods and techniques for nematology* (p. 20). Wageningen, The Netherlands: Wageningen University. http://nematologia.com.br/files/uploads/2014/03/vanBezo.pdf

Van den Berg, E., Marais, M., & Swart, A. (2017). Nematode morphology and classification. *Nematology in South Africa: a view from the 21st century*, 33-71. https://doi.org/10.1007/978-3-319-44210-5_3

Waggoner, B. M. (2020). *Introduction to the Nematoda*. Berkeley.edu. https://ucmp.berkeley.edu/phyla/ecdysozoa/nematoda.html

Wharton, D. A. (1986). A Functional Biology of Nematodes. In *Springer eBooks*. Springer Nature. https://doi.org/10.1007/978-1-4615-8516-9

Wijanarko, A., Taufik, A., & Harnowo, D. (2016). Effect of liming, manure, and NPK fertilizer application on growth and yield performance of soybean in swamp land. *Journal of Degraded and Mining Lands Management*, *3*(2), 527. https://doi.org/10.15243/jdmlm.2016.032.527

Xiao, H., Wang, W., Xia, S., Li, Z., Gan, J., & Yang, X. (2021). Distributional patterns of soil nematodes in relation to environmental variables in forest ecosystems. *Soil Ecology Letters*, *3*, 115-124. https://doi.org/10.1007/s42832-020-0069-8

Yang, W. (2017). Effect of nitrogen, phosphorus and potassium fertilizer on growth and seed germination of Capsella bursa-pastoris (L.) Medikus. *Journal of Plant Nutrition*, *41*(5), 636–644. https://doi.org/10.1080/01904167.2017.1415350

Yao, X., Guo, H., Zhang, K., Zhao, M., Ruan, J., & Chen, J. (2023). Trichoderma and its role in biological control of plant fungal and nematode disease. *Frontiers in microbiology*, *14*, 1160551. https://doi.org/10.3389/fmicb.2023.1160551

Ye, W., Robbins, R. T., & Kirkpatrick, T. (2019). Molecular characterization of root-knot nematodes (Meloidogyne spp.) from Arkansas, USA. Scientific reports, 9(1), 1-21. https://doi.org/10.1038/s41598-019-52118-4

Yeates, G. W. (2003). Nematodes as soil indicators: functional and biodiversity aspects. *Biology and Fertility of Soils*, *37*(4), 199–210. https://doi.org/10.1007/s00374-003-0586-5

Yeates, G. W., Bongers, T., De Goede, R. G., Freckman, D. W., & Georgieva, S. (1993). Feeding habits in soil nematode families and genera—an outline for soil ecologists. *Journal of nematology*, *25*(3), 315. https://pmc.ncbi.nlm.nih.gov/articles/PMC2619405/

Yeates, G. W., Ferris, H., Moens, T., & Putten, W. V. D. (2009). The role of nematodes in ecosystems. In *Nematodes as environmental indicators* (pp. 1-44). Wallingford United Kingdom: Centre for Agriculture and Bioscience International. https://doi.org/10.1079/9781845933852.0001

Zamukulu, P. M., Espoir Mukengere Bagula, Mondo, J. M., Géant Basimine Chuma, Safina, F. B., Cishesa, T. H., Kavange, A. B., Masumbuko, D. R., Kazadi, J. W., Gustave Nachigera Mushagalusa, & Lubobo, A. K. (2023). Optimization of plant density and fertilizer application to improve biofortified common bean (Phaseolus vulgaris L.) yield on Nitisols of South-Kivu, Eastern D.R. Congo. *Heliyon*, *9*(6), e17293–e17293. https://doi.org/10.1016/j.heliyon.2023.e17293

Zongo, K. F., Dabiré, K., Kaboré, S. A., Tondé, M., Guébré, D., Sanon, A., & Hien, E. Effects of Organic Compost and Trichoderma harzianum Spores on Soil Fertility and Agronomic Performance of Soybean (Glycine max (L.) Merr.). *International Journal of Environment and Climate Change*, *14*(9), 705–717. https://doi.org/10.9734/ijecc/2024/v14i94449

Zullini, A. (2018). Cosmopolitism and endemism in free-living nematodes. *Biogeographia–The Journal of Integrative Biogeography*, *33(0)*. https://doi.org/10.21426/b633034658

APPENDICES

Appendix 1: Identification Key for Major Plant-Parasitic Nematodes

As described in Mekete *et al*., (2012)

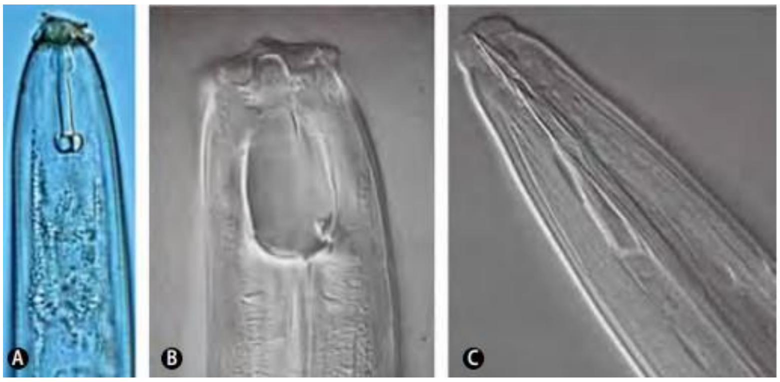

Figure 1: Stoma with stylet (A) and without (B,C)

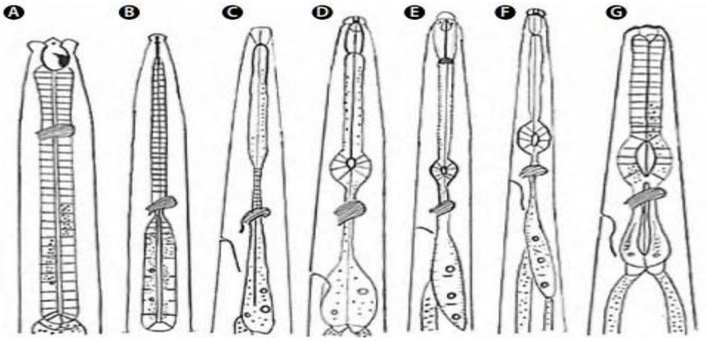

Figure 2: Different types of esophagi: one part (A), two part Dorylaimoid (B), three part (C), four part TYlenchoid (D,E,F) and four part Rhabditoid (G)

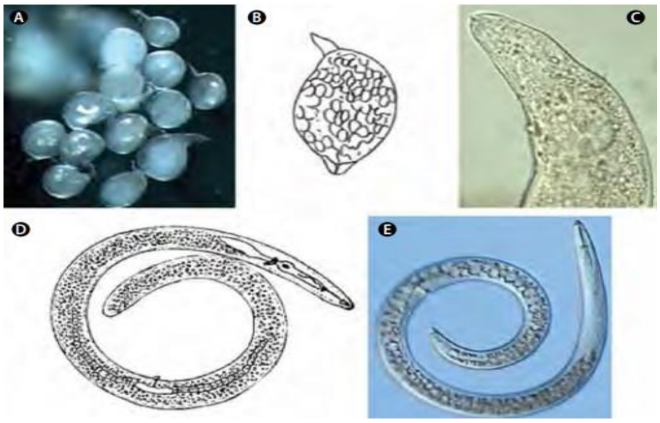

Figure 3: Female nematode body types, swollen (A, B, C) and cylindrical (D, E)

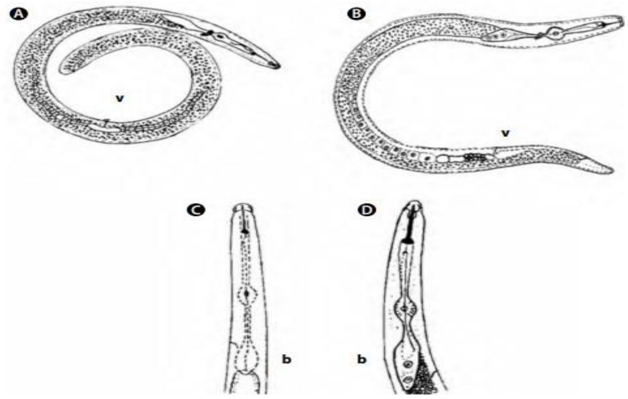

Figure 4: (A) Vulva [v] location near mid body, (B) posteriorly toward tail, (C) basal bulb [b] without overlap, and (D) intestines with overlap.

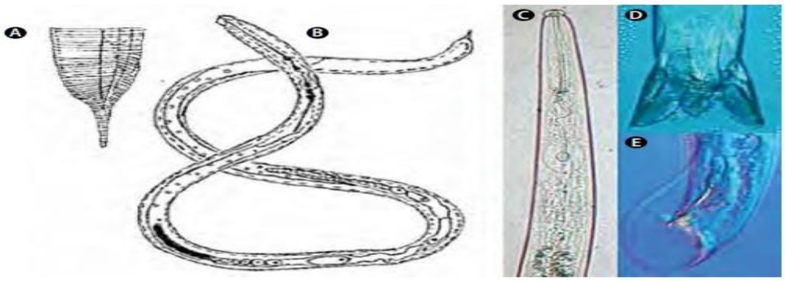

Figure 5: Dolichodorus female and juvenile tail shape (A), female full body (B), head region (C), male tail dorsal view (D), and male tail lateral view (E).

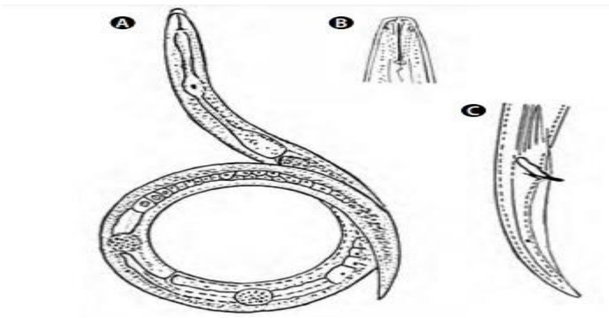

Figure 6: Merlinius female (A), stylet region (B), and male tail (C).

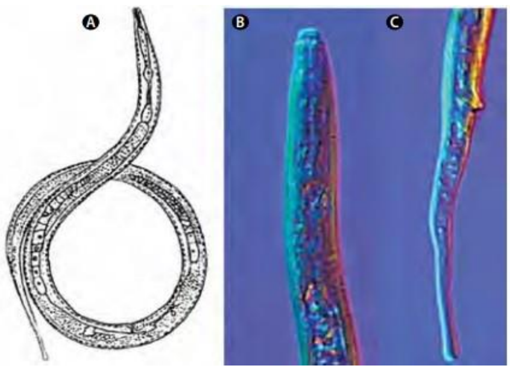

Figure 7: Psilenchus full body (A), head region (B), and male tail (C).

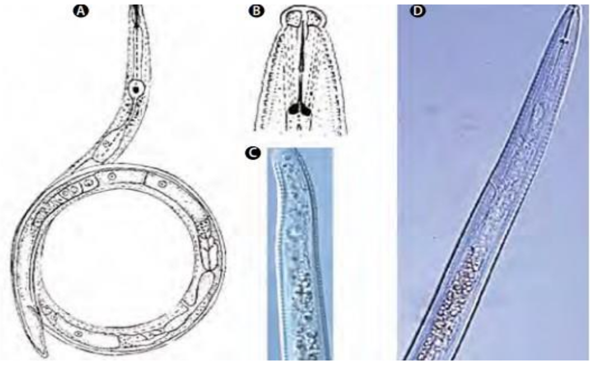

Figure 8: Tylenchorhynchus full body (A), short stylet (B), round tail tip (C), basal bulb not overlapping intestine (D).

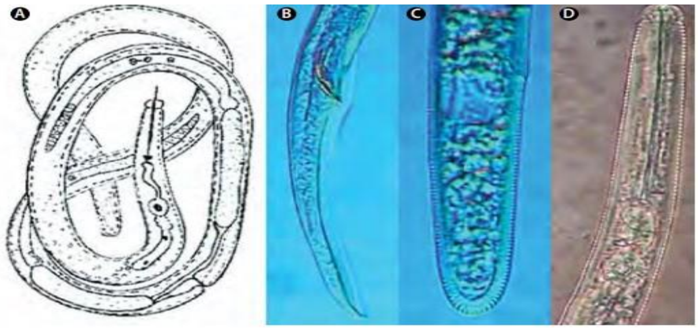

Figure 9: Belonolaimus full body length (A), male tail region (B), female tail region (C), and head region (D).

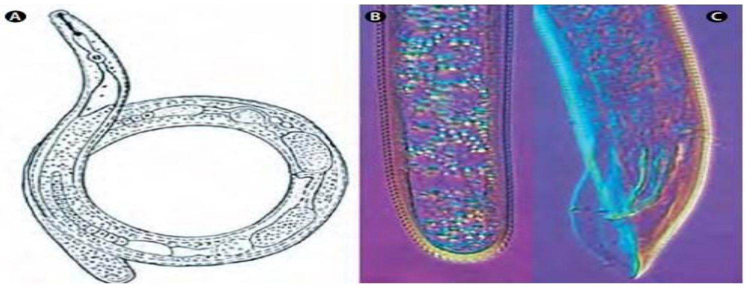

Figure 10: Hoplolaimus full body (A), female tail (B), and male tail (C).

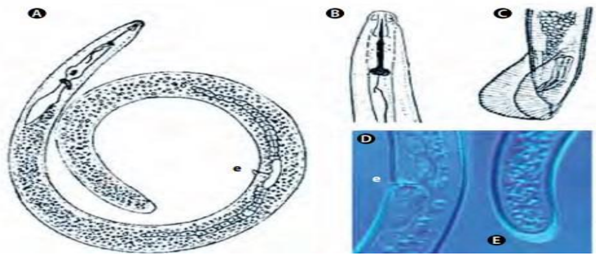

Figure 11: Peltamigratus female full body with epitygma [e] (A), stylet region (B), male tail (C), epiptygma (D), and female tail region (E).

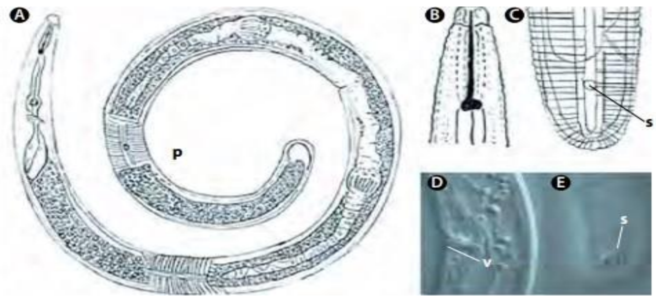

Figure 12. Aorolaimus female body with phasmid [p] midbody (A), stylet region of Aorolaimus and Scutellonema (B), tail region of Scutellonema with scutellum [s] (C), vulva [v] without epitygma (D), and scutellum [s] near tail tip of Scutellonema (E).

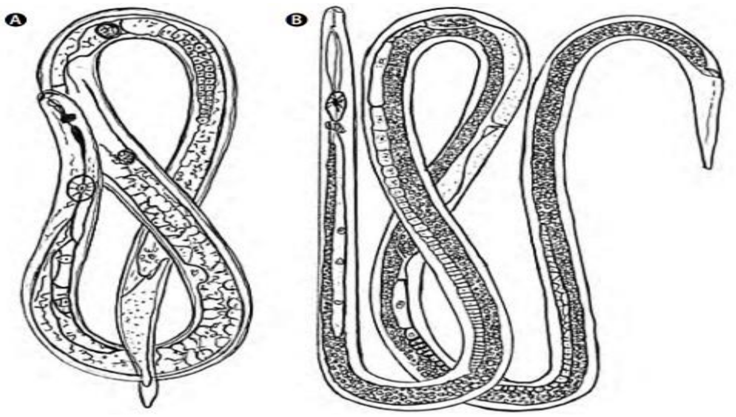

Figure 13. Female full body of Radopholus (A) and Hirschmanniella (B).

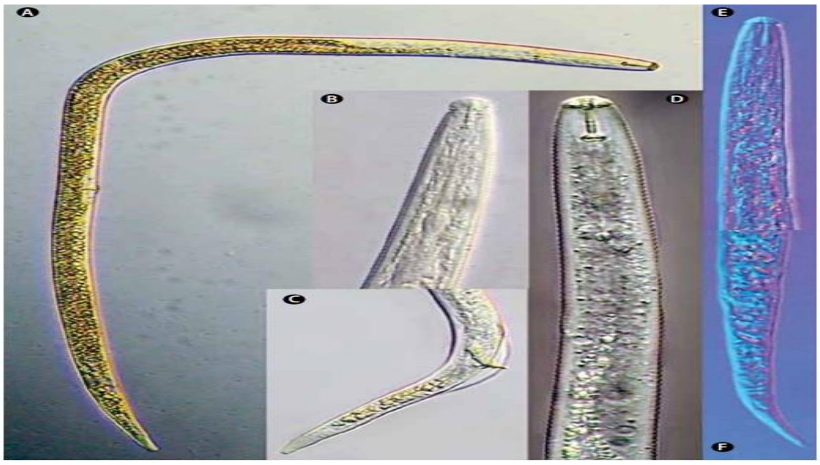

Figure 14. Radopholus mature female full body (A), male anterior head (B), male tail (C), female anterior end (D); Hirshmanniella anterior end (E) and tail region (F).

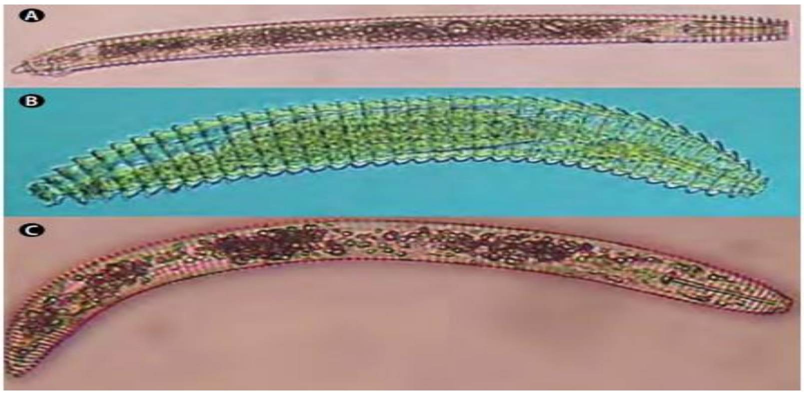

Figure 15. Entire body of Hemicriconemoides (A), Criconema (B), and Criconemella (C).

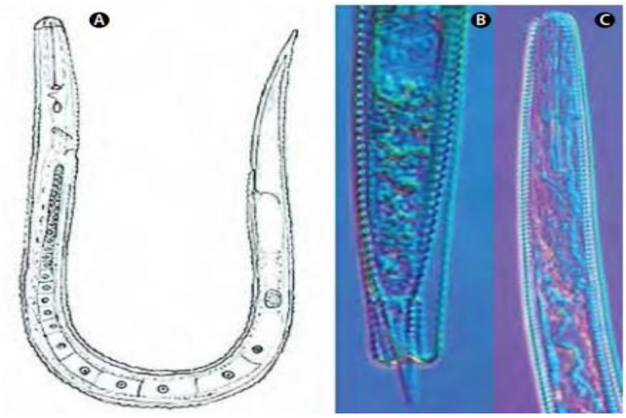

Figure 16. Hemicycliophora female full body (A), tail (B), and head (C).

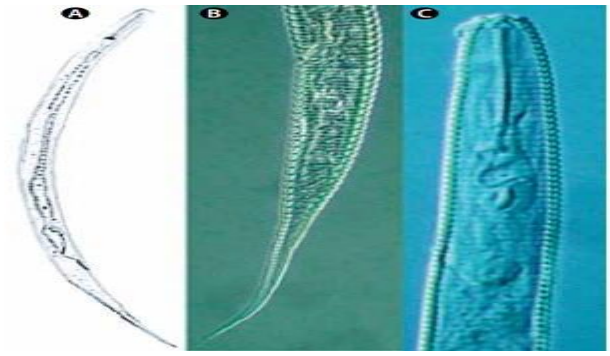

Figure 17. Caloosia female body (A), tail (B), and head (C).

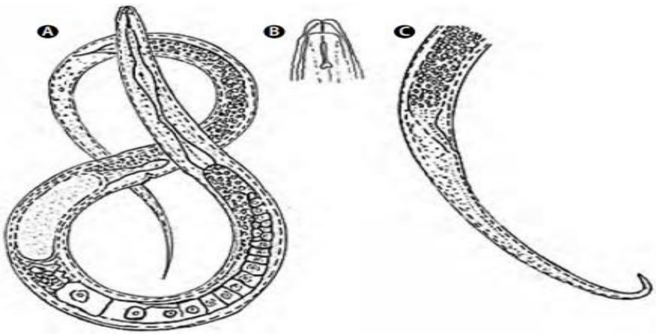

Figure 18. Tylenchulus full body view (A), stylet region (B), and tail (C).

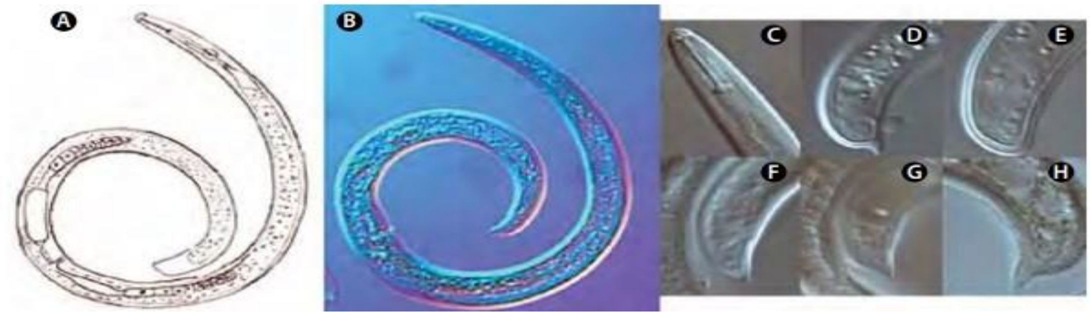

Figure 19. Full body spiral habitus of Helicotylenchus spp., (A, B), dorsal gland opening distance from stylet end (C), rounded tail with terminal projection (D), hemispherical annulated tail terminus (E), irregular tail projections (F, G), tail with non-annulated ventral projection (H).

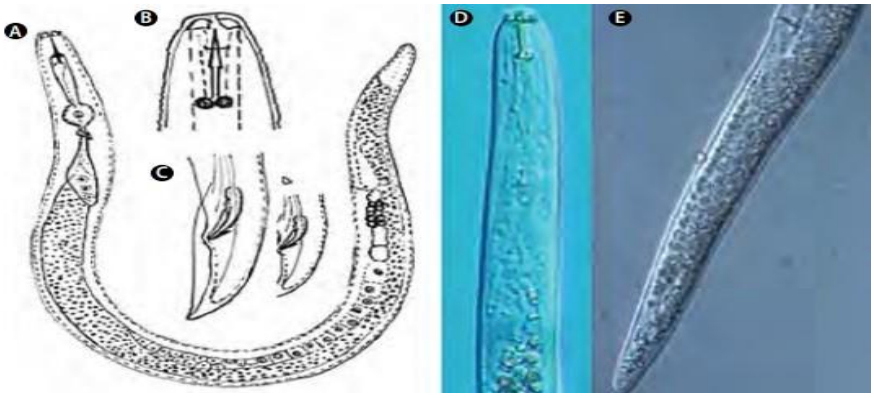

Figure 20. Pratylenchus entire body (A), head (B, D), and tail regions (C, E).

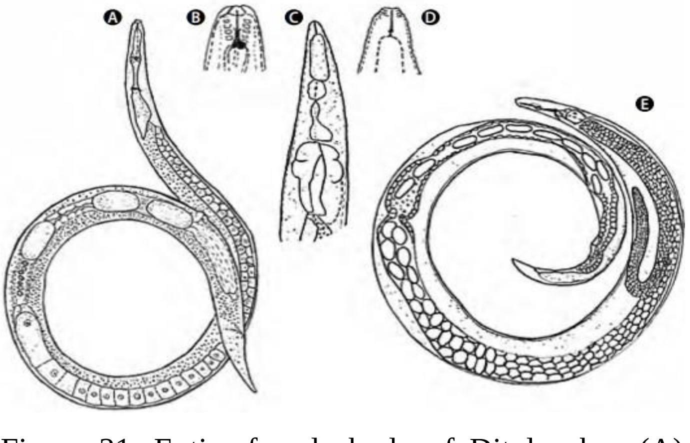

Figure 21. Entire female body of Ditylenchus (A), Ditylenchus stylet region (B), esophageal region of Anguina (C), Anguina stylet region (D), and Anguina female full body (E).

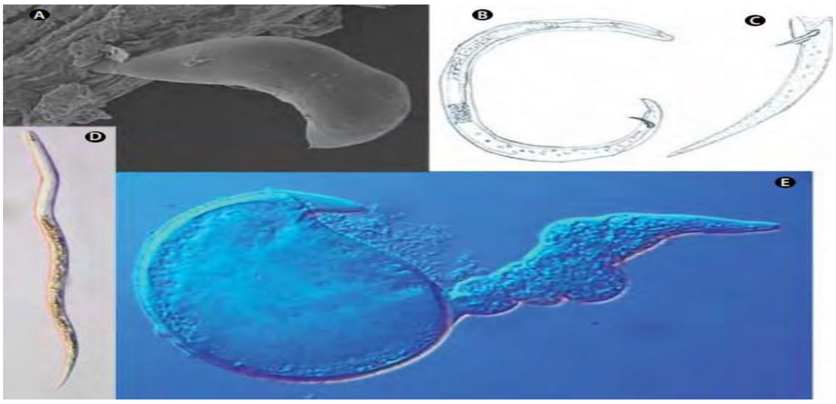

Figure 22. Rotylenchulus female protruding from root tissue (A), Rotylenchulus male full body (B) and tail region (C), Tylenchulus juvenile full body (D) and female full body extracted from root tissue (E).

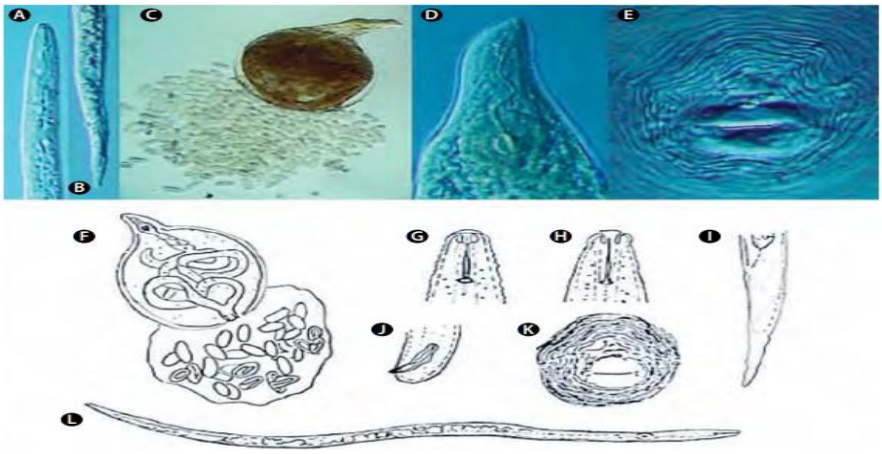

Figure 23. Meloidogyne juvenile anterior end (A), juvenile tail (B, I), mature female with eggs (C, F), mature female anterior end (D), female perineal pattern (E), male anterior end (G, H), male tail (J), perineal pattern (K), and juvenile full body (L).

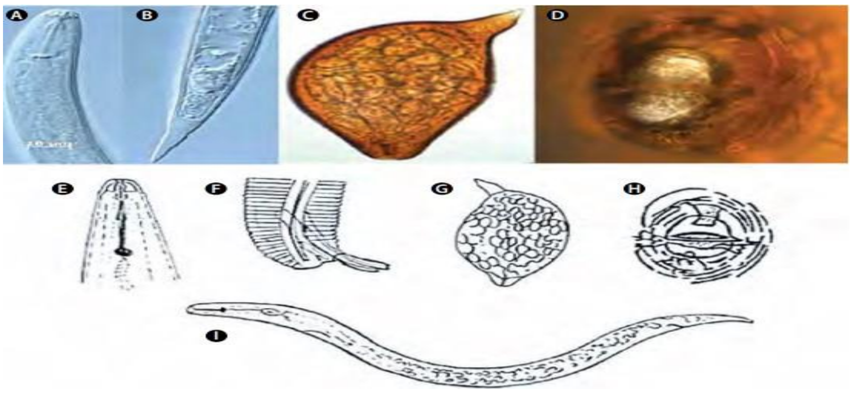

Figure 24. Heterodera juvenile anterior end (A), juvenile tail (B), mature cyst with vulval cone (C, G), vulval cone with fenestration (D, H), male anterior end (E), male tail (F), and juvenile full body (I).

Appendix 2: ANOVA of the Effect of NPK, TH, and FYM on FLN at the Initial Stage in Trial One

	DF	Sum Sq	Mean Sq	F value	Pr(>F)
Treatment	3	336096	112032	6.505	0.0258*
Replicate	2	50943	25472	1.479	0.3005
Residuals	6	103340	17223		
Total	11	490379			

Significance codes: 0 '***' 0.001 '**' 0.01 '*' 0.05 '.' 0.1 ' ' 1

Appendix 3: ANOVA of the Effect of NPK, TH, and FYM on FLN at the Flowering Stage in Trial One

	DF	Sum Sq	Mean Sq	F value	Pr(>F)
Treatment	3	35826	11942	5.666	0.0348 *
Replicate	2	18582	9291	4.408	0.0664.
Residuals	6	12646	2108		
Total	11	67054			

Significance codes: 0 '***' 0.001 '**' 0.01 '*' 0.05 '.' 0.1 ' ' 1

Appendix 4: ANOVA of the Effect of NPK, TH, and FYM on FLN at the Final Stage in Trial One

	DF	Sum Sq	Mean Sq	F value	Pr(>F)
Treatment	3	250790	83597	97.790	91e-05 ***
Replicate	2	1229	614	0.696	0.535
Residuals	6	5291	882		
Total	11	257310			

Significance codes: 0 '***' 0.001 '**' 0.01 '*' 0.05 '.' 0.1 ' ' 1

Appendix 5: ANOVA of the Effect of NPK, TH, and FYM on FLN at the Initial Stage in Trial Two

	DF	Sum Sq	Mean Sq	F value	Pr(>F)
Treatment	3	250790	83597	94.790	1.91e-05 ***
Replicate	2	1229	614	0.696	0.535
Residuals	6	5291	882		
Total	11	257310			

Significance codes: 0 '***' 0.001 '**' 0.01 '*' 0.05 '.' 0.1 ' ' 1

Appendix 6: ANOVA of the Effect of NPK, TH, and FYM on FLN at the Flowering Stage in Trial Two

	DF	Sum Sq	Mean Sq	F value	Pr(>F)
Treatment	3	1155977	385326	13.331	0.00461**
Replicate	2	17038	8519	0.295	0.75492
Residuals	6	173425	28904		
Total	11	1346440			

Significance codes: 0 '***' 0.001 '**' 0.01 '*' 0.05 '.' 0.1 ' ' 1

Appendix 7: ANOVA of the Effect of NPK, TH, and FYM on FLN at the Final Stage in Trial Two

	DF	Sum Sq	Mean Sq	F value	Pr(>F)
Treatment	3	3198176	1066059	23.913	0.000976 ***
Replicate	2	36759	18380	0.412	0.679567
Residuals	6	267488	44581		
Total	11	3502423			

Significance codes: 0 ‘***’ 0.001 ‘**’ 0.01 ‘*’ 0.05 ‘.’ 0.1 ‘ ’ 1

Appendix 8: ANOVA of the Effect of NPK, TH, and FYM on FLN at the Initial Stage in Both Trials

	DF	Sum Sq	Mean Sq	F value	Pr(>F)
Treatment	3	27523	9174	1.013	0.4207
Trial	1	49959	49959	5.519	0.0368
Treatment: Trial	3	559363	186454	20.597	5.03e-05 ***
Trial: Replicate	4	52172	13043	1.441	0.2801
Residuals	12	108632	9053		
Total	23	797649			

Significance codes: 0 ‘***’ 0.001 ‘**’ 0.01 ‘*’ 0.05 ‘.’ 0.1 ‘ ’ 1

Appendix 9: ANOVA of the Effect of NPK, TH, and FYM on FLN at the Flowering Stage in Both Trials

	DF	Sum Sq	Mean Sq	F value	Pr(>F)
Treatment	3	730861	243620	15.711	0.000186 ***
Trial	1	36738	36738	2.369	0.149684
Treatment: Trial	3	460941	153647	9.909	0.001440 **
Trial: Replicate	4	35620	8905	0.574	0.686644
Residuals	12	186071	15506		
Total	23	1450231			

Significance codes: 0 ‘***’ 0.001 ‘**’ 0.01 ‘*’ 0.05 ‘.’ 0.1 ‘ ’ 1

Appendix 10: ANOVA of the Effect of NPK, TH, and FYM on FLN at the Final Stage in Both Trials

	DF	Sum Sq	Mean Sq	F value	Pr(>F)
Treatment	3	2536477	845492	37.194	2.35e-06 ***
Trial	1	735000	735000	32.334	0.000101 ***
Treatment: Trial	3	912489	304163	13.381	0.000390 ***
Trial: Replicate	4	37988	9497	0.418	0.792802
Residuals	12	272780	22732		
Total	23	4494734			

Significance codes: 0 ‘***’ 0.001 ‘**’ 0.01 ‘*’ 0.05 ‘.’ 0.1 ‘ ’ 1

Appendix 11: ANOVA of the Effect of NPK, TH, and FYM on PPNs at the Initial Stage in Trial One

	DF	Sum Sq	Mean Sq	F value	Pr(>F)
Treatment	3	1342095	447365	73.856	3.97e-05 ***
Replicate	2	15121	7561	1.248	0.352
Residuals	6	36343	6057		
Total	11	1393559			

Significance codes: 0 ‘***’ 0.001 ‘**’ 0.01 ‘*’ 0.05 ‘.’ 0.1 ‘ ’ 1

Appendix 12: ANOVA of the Effect of NPK, TH, and FYM on PPNs at the Flowering Stage in Trial One

	DF	Sum Sq	Mean Sq	F value	Pr(>F)
Treatment	3	444144	148048	38.437	0.00026***
Replicate	2	672	336	0.087	0.01760
Residuals	6	23110	3852		
Total	11	467926			

Significance codes: 0 ‘***’ 0.001 ‘**’ 0.01 ‘*’ 0.05 ‘.’ 0.1 ‘ ’ 1

Appendix 13: ANOVA of the Effect of NPK, TH, and FYM on PPNs at the Final Stage in Trial One

	DF	Sum Sq	Mean Sq	F value	Pr(>F)
Treatment	3	96051	32017	4.813	0.0488*
Replicate	2	24295	12147	1.826	0.2402
Residuals	6	39916	6653		
Total	11	160262			

Significance codes: 0 ‘***’ 0.001 ‘**’ 0.01 ‘*’ 0.05 ‘.’ 0.1 ‘ ’ 1

Appendix 14: ANOVA of the Effect of NPK, TH, and FYM on PPNs at the Initial Stage in Trial Two

	DF	Sum Sq	Mean Sq	F value	Pr(>F)
Treatment	3	96051	32017	4.813	0.0488*
Replicate	2	24295	12147	1.826	0.2402
Residuals	6	39916	6653		
Total	11	160262			

Significance codes: 0 ‘***’ 0.001 ‘**’ 0.01 ‘*’ 0.05 ‘.’ 0.1 ‘ ’ 1

Appendix 15: ANOVA of the Effect of NPK, TH, and FYM on PPNs at the Flowering Stage in Trial Two

	DF	Sum Sq	Mean Sq	F value	Pr(>F)
Treatment	3	437034	145678	19.239	0.00176 **
Replicate	2	40034	20017	2.644	0.15021
Residuals	6	45432	7572		
Total	11	522500			

Significance codes: 0 ‘***’ 0.001 ‘**’ 0.01 ‘*’ 0.05 ‘.’ 0.1 ‘ ’ 1

Appendix 16: ANOVA of the Effect of NPK, TH, and FYM on PPNs at the Final Stage in Trial Two

	DF	Sum Sq	Mean Sq	F value	Pr(>F)
Treatment	3	2430641	810214	116.124	1.05e-05 ***
Replicate	2	295	147	0.021	0.979
Residuals	6	41863	6977		
Total	11	2472799			

Significance codes: 0 ‘***’ 0.001 ‘**’ 0.01 ‘*’ 0.05 ‘.’ 0.1 ‘ ’

Appendix 17: ANOVA of the Effect of NPK, TH, and FYM on PPNs at the Initial Stage in Both Trials

	DF	Sum Sq	Mean Sq	F value	Pr(>F)
Treatment	3	462836	154279	2.441	0.0997.
Replicate	2	16446	8223	0.130	0.8789
Trial	1	45763	45763	0.724	0.4067
Residuals	17	1074539			
Total	23	1599584			

Significance codes: 0 '***' 0.001 '**' 0.01 '*' 0.05 '.' 0.1 ' '

Appendix 18: ANOVA of the Effect of NPK, TH, and FYM on PPNs at the Flowering Stage in Both Trials

	DF	Sum Sq	Mean Sq	F value	Pr(>F)
Treatment	3	78381	26127	0.496	0.690
Replicate	2	16213	8106	0.154	0.859
Trial	1	62424	62424	1.185	0.292
Residuals	17	895832	52696		
Total	23	1052850			

Significance codes: 0 '***' 0.001 '**' 0.01 '*' 0.05 '.' 0.1 ' '

Appendix 19: ANOVA of the Effect of NPK, TH, and FYM on PPNs at the Final Stage in Both Trials

	DF	Sum Sq	Mean Sq	F value	Pr(>F)
Treatment	3	1727941	575980	10.954	0.000305 ***
Replicate	2	11269	5634	0.107	0.898984
Trial	1	83190	83190	1.582	0.225450
Residuals	17	893849	52579		
Total	23	2716249			

Significance codes: 0 '***' 0.001 '**' 0.01 '*' 0.05 '.' 0.1 ' '

Appendix 20: ANOVA of the Effect of NPK, TH, and FYM on Seed Emergence of Common Beans in Trial One

	DF	Sum Sq	Mean Sq	F value	Pr(>F)
Treatment	3	285.4	95.14	0.897	0.495
Replicate	2	313.5	156.77	1.478	0.301
Residuals	6	636.5	106.08		
Total	11	1235.4			

Appendix 21: ANOVA of the Effect of NPK, TH, and FYM on Seed Emergence of Common Beans in Trial Two

	DF	Sum Sq	Mean Sq	F value	Pr(>F)
Treatment	3	380.7	126.9	0.496	0.699
Replicate	2	501.0	250.5	0.978	0.429
Residuals	6	1536.5	256.1		
Total	11	2418.2			

Appendix 22: ANOVA of the Effect of NPK, *TH*, and FYM on Seed Emergence of Common Beans in both trials

	DF	Sum Sq	Mean Sq	F value	Pr(>F)
Trial	1	2	2.34	0.012	0.915
Treatment	3	226	75.26	0.378	0.770
REP	2	40	19.79	0.099	0.906
Residuals	17	3388	199.31		
Total	23	3656			

Appendix 23: ANOVA for Effects of NPK, FYM, and TH on Height of Common Beans at the 14th DAS in Trial One

	DF	Sum Sq	Mean Sq	F value	Pr(>F)
Treatment	3	848.25	282.75	109.33	<2e-16 ***
Replicate	2	8.37	4.19	1.62	0.210
Residuals	42	108.62	2.59		
Total	47	965.25			

Significance codes: 0 ‘***’ 0.001 ‘**’ 0.01 ‘*’ 0.05 ‘.’ 0.1 ‘ ’ 1

Appendix 24: ANOVA for Effects of NPK, FYM, and TH on Height of Common Beans at the 28th DAS in Trial One

	DF	Sum Sq	Mean Sq	F value	Pr(>F)
Treatment	3	2958.75	986.25	296.67	<2e-16 ***
Replicate	2	11.54	5.77	1.74	0.1886
Residuals	42	139.63	3.32		
Total	47	3109.92			

Significance codes: 0 ‘***’ 0.001 ‘**’ 0.01 ‘*’ 0.05 ‘.’ 0.1 ‘ ’ 1

Appendix 25: ANOVA for Effects of NPK, FYM, and TH on Height of Common Beans at the 42nd DAS in Trial One

	DF	Sum Sq	Mean Sq	F value	Pr(>F)
Treatment	3	6476.5	2158.83	352.64	<2e-16 ***
Replicate	2	18	9.02	1.47	0.2407
Residuals	42	257.1	6.12		
Total	47	6751.7			

Significance codes: 0 ‘***’ 0.001 ‘**’ 0.01 ‘*’ 0.05 ‘.’ 0.1 ‘ ’ 1

Appendix 26: ANOVA for Effects of NPK, FYM, and TH on Height of Common Beans at the 56th DAS in Trial One

	DF	Sum Sq	Mean Sq	F value	Pr(>F)
Treatment	3	11202.1	3734	286.6418	<2e-16 ***
Replicate	2	52.8	26.4	2.0263	0.1445
Residuals	42	547.1	13		
Total	47	11802			

Significance codes: 0 ‘***’ 0.001 ‘**’ 0.01 ‘*’ 0.05 ‘.’ 0.1 ‘ ’ 1

Appendix 27: ANOVA for Effects of NPK, FYM, and TH on Height of Common Beans at the 14th DAS in Trial Two

	DF	Sum Sq	Mean Sq	F value	Pr(>F)
Treatment	3	443.58	147.86	34.78	1.848e-11 ***
Replicate	2	3.79	1.90	0.446	0.6432
Residuals	42	178.54	4.251		
Total	47	625.92			

Significance codes: 0 ‘***’ 0.001 ‘**’ 0.01 ‘*’ 0.05 ‘.’ 0.1 ‘ ’ 1

Appendix 28: ANOVA for Effects of NPK, FYM, and TH on Height of Common Beans at the 28th DAS in Trial Two

	DF	Sum Sq	Mean Sq	F value	Pr(>F)
Treatment	3	16269.9	5423.3	58.2436	5.137e-15 ***
Replicate	2	184.3	92.1	0.9896	0.3802
Residuals	42	3910.8	93.1		
Total	47	20365			

Significance codes: 0 ‘***’ 0.001 ‘**’ 0.01 ‘*’ 0.05 ‘.’ 0.1 ‘ ’ 1

Appendix 29: ANOVA for Effects of NPK, FYM, and TH on Height of Common Beans at the 42nd DAS in Trial Two

	DF	Sum Sq	Mean Sq	F value	Pr(>F)
Treatment	3	24707	8235.8	26.8993	7.21e-10 ***
Replicate	2	1137	568.3	1.8562	0.1689
Residuals	42	12859	306.2		
Total	47	38703			

Significance codes: 0 ‘***’ 0.001 ‘**’ 0.01 ‘*’ 0.05 ‘.’ 0.1 ‘ ’ 1

Appendix 30: ANOVA for Effects of NPK, FYM, and TH on Height of Common Beans at the 56th DAS in Trial Two

	DF	Sum Sq	Mean Sq	F value	Pr(>F)
Treatment	3	18843	6281.2	20.9080	1.921e-08 ***
Replicate	2	673	336.4	1.1199	0.3359
Residuals	42	12618	300.4		
Total	47	32134			

Significance codes: 0 ‘***’ 0.001 ‘**’ 0.01 ‘*’ 0.05 ‘.’ 0.1 ‘’ 1

Appendix 31: ANOVA for Effects of NPK, FYM, and TH on Height of Common Beans at the 14th DAS in both Trials

	DF	Sum Sq	Mean Sq	F value	Pr(>F)
Trial	1	104.17	104.17	27.8473	9.165e-07 ***
Treatment	3	1256.67	418.89	111.9833	<2e-16 ***
Replicate	2	1.58	0.79	0.2116	0.8097
Residuals	89	332.92	3.74		
Total	95	1695.33			

Significance codes: 0 ‘***’ 0.001 ‘**’ 0.01 ‘*’ 0.05 ‘.’ 0.1 ‘’ 1

Appendix 32: ANOVA for Effects of NPK, FYM, and TH on Height of Common Beans at the 28^{th} DAS in Both Trials

	DF	Sum Sq	Mean Sq	F value	Pr(>F)
Trial	1	527.3	527.3	6.4273	0.01298 *
Treatment	3	16082.3	5360.8	65.3374	<2e-16 ***
Replicate	2	90.4	45.2	0.5509	0.57840
Residuals	89	7302.2	82		
Total	95	24002.2			

Significance codes: 0 ‘***’ 0.001 ‘**’ 0.01 ‘*’ 0.05 ‘.’ 0.1 ‘ ’ 1

Appendix 33: ANOVA for Effects of NPK, FYM, and TH on Height of Common Beans at the 42^{nd} DAS in Both Trials

	DF	Sum Sq	Mean Sq	F value	Pr (>F)
Trial	1	25026	25026	134.5693	<2e-16 ***
Treatment	3	28227	9409.1	50.5945	<2e-16 ***
Replicate	2	676	338	1.8177	0.1684
Residuals	89	16551	186		
Total	95	70481			

Significance codes: 0 ‘***’ 0.001 ‘**’ 0.01 ‘*’ 0.05 ‘.’ 0.1 ‘ ’ 1

Appendix 34: ANOVA for Effects of NPK, FYM, and TH on Height of Common Beans at the 56^{th} DAS in Both Trials

	DF	Sum Sq	Mean Sq	F value	Pr(>F)
Trial	1	22113	22113	141.5465	<2e-16 ***
Treatment	3	29481	9827.1	62.9039	<2e-16 ***
Replicate	2	551	275.3	1.7624	0.1776
Residuals	89	13904	156.2		
Total	95	66049			

Significance codes: 0 ‘***’ 0.001 ‘**’ 0.01 ‘*’ 0.05 ‘.’ 0.1 ‘ ’ 1

Appendix 35: ANOVA for Effects of NPK, FYM, and TH on Number of Leaves of Common Beans at the 14^{th} DAS in Trial One

	DF	Sum Sq	Mean Sq	F value	Pr(>F)
Treatment	3	45.75	15.25	9.1337	8.982e-05 ***
Replicate	2	9.38	4.68	2.8075	0.07172 .
Residuals	42	70.13	1.67		
Total	47	125.25			

Significance codes: 0 ‘***’ 0.001 ‘**’ 0.01 ‘*’ 0.05 ‘.’ 0.1 ‘ ’ 1

Appendix 36: ANOVA for Effects of NPK, FYM, and TH on Number of Leaves of Common Beans at the 28^{th} DAS in Trial One

	DF	Sum Sq	Mean Sq	F value	Pr(>F)
Treatment	3	2072.06	690.69	48.1375	1.194e-13 ***
Replicate	2	286.12	143.06	9.9708	0.0002862 ***
Residuals	42	602.62	14.35		
Total	47	2960.81			

Significance codes: 0 ‘***’ 0.001 ‘**’ 0.01 ‘*’ 0.05 ‘.’ 0.1 ‘ ’ 1

Appendix 37: ANOVA for Effects of NPK, FYM, and TH on Number of Leaves of Common Beans at the 42nd DAS in Trial One

	DF	Sum Sq	Mean Sq	F value	Pr(>F)
Treatment	3	4844.2	1614.75	83.265	< 2.2e-16 ***
Replicate	2	514.5	257.25	13.265	3.425e-05 ***
Residuals	42	814.5	19.39		
Total	47	6173.2			

Significance codes: 0 ‘***’ 0.001 ‘**’ 0.01 ‘*’ 0.05 ‘.’ 0.1 ‘ ’ 1

Appendix 38: ANOVA for Effects of NPK, FYM, and TH on Number of Leaves of Common Beans at the 56th DAS in Trial One

	DF	Sum Sq	Mean Sq	F value	Pr(>F)
Treatment	3	6218.1	2072.69	48.052	1.228e-13 ***
Replicate	2	947.6	473.81	10.985	0.0001455 ***
Residuals	42	1811.6	43.13		
Total	47	8977.3			

Significance codes: 0 ‘***’ 0.001 ‘**’ 0.01 ‘*’ 0.05 ‘.’ 0.1 ‘ ’ 1

Appendix 39: ANOVA for Effects of NPK, FYM, and TH on Number of Leaves of Common Beans at the 14th DAS in Trial Two

	DF	Sum Sq	Mean Sq	F value	Pr(>F)
Treatment	3	45.75	15.25	12.5588	5.364e-06 ***
Replicate	2	10.50	5.25	4.3235	0.01962 *
Residuals	42	51	1.21		
Total	47	107.25			

Significance codes: 0 ‘***’ 0.001 ‘**’ 0.01 ‘*’ 0.05 ‘.’ 0.1 ‘ ’ 1

Appendix 40: ANOVA for Effects of NPK, FYM, and TH on Number of Leaves of Common Beans at the 28th DAS in Trial Two

	DF	Sum Sq	Mean Sq	F value	Pr(>F)
Treatment	3	2382.0	794.0	130.202	< 2.2e-16 ***
Replicate	2	148.9	74.44	12.206	6.62e-05 ***
Residuals	42	245.6	6.10		
Total	47	2787			

Significance codes: 0 ‘***’ 0.001 ‘**’ 0.01 ‘*’ 0.05 ‘.’ 0.1 ‘ ’ 1

Appendix 41: ANOVA for Effects of NPK, FYM, and TH on Number of Leaves of Common Beans at the 42nd DAS in Trial Two

	DF	Sum Sq	Mean Sq	F value	Pr(>F)
Treatment	3	31861	10620.2	95.4399	<2e-16 ***
Replicate	2	251	125.4	1.1273	0.3335
Residuals	42	4647	111.3		
Total	47	36785			

Significance codes: 0 ‘***’ 0.001 ‘**’ 0.01 ‘*’ 0.05 ‘.’ 0.1 ‘ ’ 1

Appendix 42: ANOVA for Effects of NPK, FYM, and TH on Number of Leaves of Common Beans at the 56th DAS in Trial Two

	DF	Sum Sq	Mean Sq	F value	Pr(>F)
Treatment	3	38671	12890.2	74.7993	<2e-16 ***
Replicate	2	35	17.4	0.1012	0.904
Residuals	42	7238	172.3		
Total	47	45943			

Significance codes: 0 '***' 0.001 '**' 0.01 '*' 0.05 '.' 0.1 ' ' 1

Appendix 43: ANOVA for Effects of NPK, FYM, and TH on Number of Leaves of Common Beans at the 14th DAS, Both Trials

	DF	Sum Sq	Mean Sq	F value	Pr(>F)
Trial	1	253.50	253.50	182.592	< 2.2e-16 ***
Treatment	3	91.50	30.50	21.969	9.791e-11 ***
Replicate	2	17.44	8.72	6.280	0.00281 **
Residuals	89	123.56	1.39		
Total	95	486			

Significance codes: 0 '***' 0.001 '**' 0.01 '*' 0.05 '.' 0.1 ' ' 1

Appendix 44: ANOVA for Effects of NPK, FYM, and TH on Number of Leaves of Common Beans at the 28th DAS, Both Trials

	DF	Sum Sq	Mean Sq	F value	Pr(>F)
Trial	1	41.3	41.34	4.0711	0.04664 *
Treatment	3	4441	1480.34	145.7670	< 2.2e-16 ***
Replicate	2	402.9	201.47	19.8383	7.501e-08 ***
Residuals	89	903.8	10.16		
Total	95	5789.2			

Significance codes: 0 '***' 0.001 '**' 0.01 '*' 0.05 '.' 0.1 ' ' 1

Appendix 45: ANOVA for Effects of NPK, FYM, and TH on Number of Leaves of Common Beans at the 42nd DAS, Both Trials

	DF	Sum Sq	Mean Sq	F value	Pr(>F)
Trial	1	9362	9361.5	70.7725	6.152e-13 ***
Treatment	3	30677	10225.8	77.3062	< 2.2e-16 ***
Replicate	2	509	254.3	1.9228	0.1522
Residuals	89	11773	132.3		
Total	95	52320			

Significance codes: 0 '***' 0.001 '**' 0.01 '*' 0.05 '.' 0.1 ' ' 1

Appendix 46: ANOVA for Effects of NPK, FYM, and TH on Number of Leaves of Common Beans at the 56th DAS, Both Trials

	DF	Sum Sq	Mean Sq	F value	Pr (>F)
Trial	1	16695	16695.4	89.8894	3.791e-15 ***
Treatment	3	37760	12586.8	67.7682	< 2.2e-16 ***
Replicate	2	630	315.1	1.6965	0.1892
Residuals	89	16530	185.7		
Total	95	71616			

Significance codes: 0 '***' 0.001 '**' 0.01 '*' 0.05 '.' 0.1 ' ' 1

Appendix 47: ANOVA for Effects of NPK, FYM, and TH on Number of Branches of Common Beans at the 14th DAS in Trial One

	DF	Sum Sq	Mean Sq	F value	Pr (>F)
Treatment	3	5.08	1.69	9.1337	8.982e-05 ***
Replicate	2	1.04	0.52	2.8075	0.07172 .
Residuals	42	7.79	0.19		
Total	47	13.92			

Significance codes: 0 ‘***’ 0.001 ‘**’ 0.01 ‘*’ 0.05 ‘.’ 0.1 ‘ ’ 1

Appendix 48: ANOVA for Effects of NPK, FYM, and TH on Number of Branches of Common Beans at the 28th DAS in Trial One

	DF	Sum Sq	Mean Sq	F value	Pr (>F)
Treatment	3	230.23	76.74	48.1375	2.45e-13 ***
Replicate	2	31.79	15.90	9.9708	0.0002862 ***
Residuals	42	66.96	1.59		
Total	47	328.98			

Significance codes: 0 ‘***’ 0.001 ‘**’ 0.01 ‘*’ 0.05 ‘.’ 0.1 ‘ ’ 1

Appendix 49: ANOVA for Effects of NPK, FYM, and TH on Number of Branches of Common Beans at the 42nd DAS in Trial One

	DF	Sum Sq	Mean Sq	F value	Pr (>F)
Treatment	3	538.25	179.42	83.265	< 2e-16 ***
Replicate	2	57.17	28.58	13.265	3.425e-05 ***
Residuals	42	90.50	2.15		
Total	47	685.92			

Significance codes: 0 ‘***’ 0.001 ‘**’ 0.01 ‘*’ 0.05 ‘.’ 0.1 ‘ ’ 1

Appendix 50: ANOVA for Effects of NPK, FYM, and TH on Number of Branches of Common Beans at the 56th DAS in Trial One

	DF	Sum Sq	Mean Sq	F value	Pr (>F)
Treatment	3	692.7	230.91	50.987	4.683e-14 ***
Replicate	2	113.37	56.69	12.517	5.445e-05 ***
Residuals	42	190.21	4.53		
Total	47	996.31			

Significance codes: 0 ‘***’ 0.001 ‘**’ 0.01 ‘*’ 0.05 ‘.’ 0.1 ‘ ’ 1

Appendix 51: ANOVA for Effects of NPK, FYM, and TH on Number of Branches of Common Beans at the 14th DAS in Trial Two

	DF	Sum Sq	Mean Sq	F value	Pr (>F)
Treatment	3	5.08	1.69	12.56	5.364e-06 ***
Replicate	2	1.17	0.58	4.32	0.01962 *
Residuals	42	5.67	0.13		
Total	47	11.92			

Significance codes: 0 ‘***’ 0.001 ‘**’ 0.01 ‘*’ 0.05 ‘.’ 0.1 ‘ ’ 1

Appendix 52: ANOVA for Effects of NPK, FYM, and TH on Number of Branches of Common Beans at the 28th DAS in Trial Two

	DF	Sum Sq	Mean Sq	F value	Pr (>F)
Treatment	3	264.67	88.22	130.202	< 2e-16 ***
Replicate	2	16.54	8.27	12.206	6.621e-05 ***
Residuals	42	28.46	0.68		
Total	47	309.67			

Significance codes: 0 '***' 0.001 '**' 0.01 '*' 0.05 '.' 0.1 ' ' 1

Appendix 53: ANOVA for Effects of NPK, FYM, and TH on Number of Branches of Common Beans at the 42nd DAS in Trial Two

	DF	Sum Sq	Mean Sq	F value	Pr (>F)
Treatment	3	3540.1	1180.03	95.4399	<2e-16 ***
Replicate	2	27.9	13.94	1.1273	0.3335
Residuals	42	519.3	12.36		
Total	47	4087.2			

Significance codes: 0 '***' 0.001 '**' 0.01 '*' 0.05 '.' 0.1 ' ' 1

Appendix 54: ANOVA for Effects of NPK, FYM, and TH on Number of Branches of Common Beans at the 56th DAS in Trial Two

	DF	Sum Sq	Mean Sq	F value	Pr (>F)
Treatment	3	4296.7	1432.24	74.7993	<2e-16 ***
Replicate	2	3.9	1.94	0.1012	0.904
Residuals	42	804.2	19.15		
Total	47	5104.8			

Significance codes: 0 '***' 0.001 '**' 0.01 '*' 0.05 '.' 0.1 ' ' 1

Appendix 55: ANOVA for Effects of NPK, FYM, and TH on Number of Branches of Common Beans at the 14th DAS in Both Trials

	DF	Sum Sq	Mean Sq	F value	Pr (>F)
Trial	1	28.167	28.167	182.59	< 2.2e-16 ***
Treatment	3	10.167	3.3889	21.969	9.791e-11 ***
Replicate	2	1.937	0.969	6.280	0.00218 **
Residuals	89	13.729	0.15		
Total	95	54			

Significance codes: 0 '***' 0.001 '**' 0.01 '*' 0.05 '.' 0.1 ' ' 1

Appendix 56: ANOVA for Effects of NPK, FYM, and TH on Number of Branches of Common Beans at the 28th DAS in Both Trials

	DF	Sum Sq	Mean Sq	F value	Pr (>F)
Trial	1	4.59	4.59	4.O711	0.04664 *
Treatment	3	493.45	164.48	145.7670	< 2.2e-16 ***
Replicate	2	44.77	22.39	19.8383	7.501e-08 ***
Residuals	89	100.43	1.10		
Total	95	643.24	1.13		

Significance codes: 0 '***' 0.001 '**' 0.01 '*' 0.05 '.' 0.1 ' ' 1

Appendix 57: ANOVA for Effects of NPK, FYM, and TH on Number of Branches of Common Beans at the 42nd DAS in Both Trials

	DF	Sum Sq	Mean Sq	F value	Pr (>F)
Trial	1	1040.2	1040.17	70.7725	6.152e-13 ***
Treatment	3	3408.6	1136.19	77.3062	< 2.2e-16 ***
Replicate	2	56.5	28.26	1.9228	0.1522
Residuals	89	1308.1	14.70		
Total	95	5813.3			

Significance codes: 0 '***' 0.001 '**' 0.01 '*' 0.05 '.' 0.1 ' ' 1

Appendix 58: ANOVA for Effects of NPK, FYM, and TH on Number of Branches of Common Beans at the 56th DAS in Both Trials

	DF	Sum Sq	Mean Sq	F value	Pr (>F)
Trial	1	1837.5	1837.5	89.6372	4.039e-15***
Treatment	3	4201.9	1400.63	68.3255	< 2.2e-16 ***
Replicate	2	74.8	37.41	1.8248	0.1672
Residuals	89	1824.4	20.50		
Total	95	7938.6			

Significance codes: 0 '***' 0.001 '**' 0.01 '*' 0.05 '.' 0.1 ' ' 1

Appendix 59: ANOVA for Effects of NPK, FYM, and TH on the number of pods of Common Beans in Trial One

	DF	Sum Sq	Mean Sq	F value	Pr(>F)
Treatment	3	6061.4	2020.5	219.8488	<2e-16 ***
Replicate	2	6.6	3.32	0.3615	0.6972
Residuals	114	1047	9.19		
Total	119	7115.7			

Significance codes: 0 '***' 0.001 '**' 0.01 '*' 0.05 '.' 0.1 ' ' 1

Appendix 60: ANOVA for Effects of NPK, FYM, and TH on Number of Pods of Common Beans in Trial Two

	DF	Sum Sq	Mean Sq	F value	Pr(>F)
Treatment	3	6594.2	2198.05	241.0872	<2e-16 ***
Replicate	2	55.8	27.9	3.0601	0.05075 .
Residuals	114	1039.4	9.12		
Total	119	7689.3			

Significance codes: 0 '***' 0.001 '**' 0.01 '*' 0.05 '.' 0.1 ' ' 1

Appendix 61: ANOVA for Effects of NPK, FYM, and TH on Number of Pods of Common Beans in Both Trials

	DF	Sum Sq	Mean Sq	F value	Pr(>F)
Trial	1	3	3	0.3342	0.5638
Treatment	3	12647.5	4215.8	463.7822	<2e-16 ***
Replicate	2	39.5	19.7	2.1713	0.1163
Residuals	233	2118	9.1		
Total	239	14808.1			

Significance codes: 0 '***' 0.001 '**' 0.01 '*' 0.05 '.' 0.1 ' ' 1

Appendix 62: ANOVA for Effects of NPK, FYM, and TH on Number of Seeds of Common beans in Trial One

	DF	Sum Sq	Mean Sq	F value	Pr(>F)
Treatment	3	359597	119866	145.9167	< 2.2e-16 ***
Replicate	2	10244	5122	6.2353	0.002693 **
Residuals	114	93647	821		
Total	119	463489			

Significance codes: 0 ‘***’ 0.001 ‘**’ 0.01 ‘*’ 0.05 ‘.’ 0.1 ‘ ’ 1

Appendix 63: ANOVA for Effects of NPK, FYM, and TH on Number of Seeds of Common beans in Trial Two

	DF	Sum Sq	Mean Sq	F value	Pr(>F)
Treatment	3	282889	94296	216.8836	<2e-16 ***
Replicate	2	969	485	1.1145	0.3316
Residuals	114	49565	435		
Total	119	333422			

Significance codes: 0 ‘***’ 0.001 ‘**’ 0.01 ‘*’ 0.05 ‘.’ 0.1 ‘ ’ 1

Appendix 64: ANOVA for Effects of NPK, FYM, and TH on Number of Seeds of Common beans in Both Trials

	DF	Sum Sq	Mean Sq	F value	Pr(>F)
Trial	1	1728	1728	2.6680	0.10581
Treatment	3	639170	213057	328.9388	< 2.2e-16 ***
Replicate	2	6825	3412	5.2684	0.005784 **
Residuals	233	150916	648		
Total	239	798639			

Significance codes: 0 ‘***’ 0.001 ‘**’ 0.01 ‘*’ 0.05 ‘.’ 0.1 ‘ ’ 1

Appendix 65: ANOVA for Effects of NPK, FYM, and TH on Yield of Common Beans in Trial One

	DF	Sum Sq	Mean Sq	F value	Pr(>F)
Treatment	3	23220966	7740322	15.70	0.00302 **
Replicate	2	1035469	517735	1.05	0.40644
Residuals	6	2958445	493074		
Total	11	27214880			

Significance codes: 0 ‘***’ 0.001 ‘**’ 0.01 ‘*’ 0.05 ‘.’ 0.1 ‘ ’ 1

Appendix 66: ANOVA for Effects of NPK, FYM, and TH on Yield of Common Beans in Trial Two

	DF	Sum Sq	Mean Sq	F value	Pr(>F)
Treatment	3	27427082	9142361	11.16	0.00723 **
Replicate	2	2900776	1450388	1.77	0.24876
Residuals	6	4916330	819388		
Total	11	35244188			

Significance codes: 0 ‘***’ 0.001 ‘**’ 0.01 ‘*’ 0.05 ‘.’ 0.1 ‘ ’ 1

Appendix 67: ANOVA for Effects of NPK, FYM, and TH on Yield of Common Beans in Both Trials

	DF	Sum Sq	Mean Sq	F value	Pr(>F)
Trial	1	1731616	1731616	3.55	0.0768 .
Treatment	3	50556934	16852311	34.55	1.87e-07 ***
Replicate	2	3609499	1804750	3.70	0.0464 *
Residuals	17	8292635	487802		
Total	23	64190684			

Significance codes: 0 '***' 0.001 '**' 0.01 '*' 0.05 '.' 0.1 ' ' 1

Appendix 68: ANOVA for Effects of NPK, FYM, and TH on Biomass of Common beans in Trial One

	DF	Sum Sq	Mean Sq	F value	Pr(>F)
Treatment	3	1989632	663211	64.529	5.88e-05 ***
Replicate	2	16097	8049	0.783	0.499
Residuals	6	61666	10278		
Total	11	2067395			

Significance codes: 0 '***' 0.001 '**' 0.01 '*' 0.05 '.' 0.1 ' ' 1

Appendix 69: ANOVA for Effects of NPK, FYM, and TH on Biomass of Common Beans in Trial Two

	DF	Sum Sq	Mean Sq	F value	Pr(>F)
Treatment	3	1637175	545725	122.991	8.91e-06 ***
Replicate	2	7873	3937	0.887	0.46
Residuals	6	26623	4437		
Total	11	1671671			

Significance codes: 0 '***' 0.001 '**' 0.01 '*' 0.05 '.' 0.1 ' ' 1

Appendix 70: ANOVA for Effects of NPK, FYM, and TH on Biomass of Common beans in Both Trials

	DF	Sum Sq	Mean Sq	F value	Pr(>F)
Trial	1	2136	2136	0.323	0.577
Treatment	3	3603740	1201247	181.431	4.17e-13 ***
Replicate	2	22770	11385	1.720	0.209
Residuals	17	112556	6621		
Totals	23	3741202			

Significance codes: 0 '***' 0.001 '**' 0.01 '*' 0.05 '.' 0.1 ' ' 1

Appendix 71: ANOVA for Effect of NPK, FYM, and TH on Number of Nodules in Common Beans in Trial One

	DF	Sum Sq	Mean Sq	F value	Pr(>F)
Treatment	3	8290.9	2763.63	42.8003	5.877e-11 ***
Replicate	2	160.2	80.11	1.2407	0.3036
Residuals	30	1937.1	64.57		
Total	35	10388.2			

Significance codes: 0 '***' 0.001 '**' 0.01 '*' 0.05 '.' 0.1 ' ' 1

Appendix 72: ANOVA for Effect of NPK, FYM, and TH on Number of Nodules in Common Beans in Trial Two

	DF	Sum Sq	Mean Sq	F value	Pr(>F)
Treatment	3	15809.9	5270	240.292	< 2.2e-16 ***
Replicate	2	693.2	346.6	15.803	2.053e-05 ***
Residuals	30	657.9	21.9		
Total	35	17161.0			

Significance codes: 0 ‘***’ 0.001 ‘**’ 0.01 ‘*’ 0.05 ‘.’ 0.1 ‘ ’ 1

Appendix 73: ANOVA for Effect of NPK, Fym, and *Th* on Number of Nodules in Common Beans in Both Trials

	DF	Sum Sq	Mean Sq	F value	Pr(>F)
Trial	1	2913.4	2913.4	50.1713	1.237e-09 ***
Treatment	3	23138.4	7712.8	132.8217	< 2.2e-16 ***
Replicate	2	636.4	318.2	5.4794	0.006323 **
Residuals	65	3774.5	58.1		
Total	71	30462.6			

Significance codes: 0 ‘***’ 0.001 ‘**’ 0.01 ‘*’ 0.05 ‘.’ 0.1 ‘ ’ 1

Appendix 74: ANOVA for Effect of NPK, FYM, and TH on PPNs in Roots of Common Beans in Trial One

	DF	Sum Sq	Mean Sq	F value	Pr(>F)
Treatment	3	3721	1240.4	4.776	0.00496*
Replicate	2	133	66.3	0.255	0.7827
Residuals	6	1558	259.7		
Total	11	5412			

Significance codes: 0 ‘***’ 0.001 ‘**’ 0.01 ‘*’ 0.05 ‘.’ 0.1 ‘ ’ 1

Appendix 75: ANOVA for Effect of NPK, FYM, and TH on PPNs in Roots of Common Beans in Trial Two

	DF	Sum Sq	Mean Sq	F value	Pr(>F)
Treatment	3	7388	2462.8	36.575	0.000299 ***
Replicate	2	248	124.0	1.842	0.237904
Residuals	6	404	67.3		
Total	11	8040			

Significance codes: 0 ‘***’ 0.001 ‘**’ 0.01 ‘*’ 0.05 ‘.’ 0.1 ‘ ’ 1

Appendix 76: ANOVA for Effect of NPK, FYM, and TH on PPNs in Roots of Common Beans in Both Trials

	DF	Sum Sq	Mean Sq	F value	Pr(>F)
Treatment	3	9488	3163	19.341	6.86e-05 ***
Trial	1	1610	1610	9.848	0.00856 **
Trial: Replicate	4	381	95	0.582	0.68161
Treatment: Trial	3	1622	541	3.306	0.05741 .
Residuals	12	1962	164		
Total	23	15063			

Significance codes: 0 ‘***’ 0.001 ‘**’ 0.01 ‘*’ 0.05 ‘.’ 0.1 ‘ ’ 1

Appendix 77: Pictorial Presentation of Field Experiment and Laboratory Work

Appendix 78: Chuka University Ethics Approval letter

CHUKA UNIVERSITY

Knowledge is Wealth *(Sapientia divitia est)* Akili ni Mali

CHUKA UNIVERSITY INSTITUTIONAL ETHICS REVIEW COMMITTEE

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P. O. Box 109-60400, Chuka
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19th March, 2024

REF: CUIERC/ NACOSTI/490
TO: **Margaret Wairimu Muraki**

RE: Soil Nematode Communities under Different Fertility Management Practices, Biocontrol, Growth and Yield of Common Beans (var.Mwitemania) in Tharaka Nithi, Kenya

This is to inform you that *Chuka University IERC* has reviewed and approved your above research proposal. Your application approval number is *NACOSTI/NBC/AC-0812*. The approval period is 19th March, 2024 – 19th March, 2025.

This approval is subject to compliance with the following requirements;

i. Only approved documents including (informed consents, study instruments, MTA) will be used
ii. All changes including (amendments, deviations, and violations) are submitted for review and approval by *Chuka University IERC*.
iii. Death and life threatening problems and serious adverse events or unexpected adverse events whether related or unrelated to the study must be reported to *Chuka University IERC* within 72 hours of notification
iv. Any changes, anticipated or otherwise that may increase the risks or affected safety or welfare of study participants and others or affect the integrity of the research must be reported to *Chuka University IERC* within 72 hours
v. Clearance for export of biological specimens must be obtained from relevant institutions.
vi. Submission of a request for renewal of approval at least 60 days prior to expiry of the approval period. Attach a comprehensive progress report to support the renewal.
vii. Submission of an executive summary report within 90 days upon completion of the study to *Chuka University IERC*.

Prior to commencing your study, you will be expected to obtain a research license from National Commission for Science, Technology and Innovation (NACOSTI) https://oris.nacosti.go.ke and also obtain other clearances needed.

Yours sincerely

Dr. Benjamin Kanga
SECRETARY

Appendix 79: NARCOSTI Research Permit

REPUBLIC OF KENYA

NATIONAL COMMISSION FOR SCIENCE,TECHNOLOGY & INNOVATION

Ref No: **197878**

Date of Issue: **06/May/2024**

RESEARCH LICENSE

This is to Certify that Miss.. Margaret Wairimu Muraki of Chuka University, has been licensed to conduct research as per the provision of the Science, Technology and Innovation Act, 2013 (Rev.2014) in Tharaka-Nithi on the topic: SOIL NEMATODE COMMUNITIES UNDER DIFFERENT FERTILITY MANAGEMENT PRACTICES, BIOCONTROL, GROWTH AND YIELD OF COMMON BEANS (var. Mwitemania) IN THARAKA NITHI, KENYA for the period ending : 06/May/2025.

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197878

Applicant Identification Number

Director General

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